EFFECT OF STRETCHABLE CONDUCTIVE INK DIMENSIONS ON ELECTRICAL CONDUCTIVITY

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A report submitted
in fulfillment of the requirements for the Degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering

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DECLARATION

I hereby declare that Final Year Project Report submitted to the Universiti Teknikal Malaysia Melaka (UTeM) is a record of an original work done and this report submitted in the part of the fulfillment of the requirements for the award of the degree of Bachelor Mechanical Engineering Hons. If any discrepancy is found regarding the originality of this project I may be held responsible. I have not copied from any report submitted earlier this or any other university. This is purely original and authentic work.

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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Bachelor of Mechanical Engineering with Honours.

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I would like to dedicate my thesis to my beloved parents and my supervisor who gave me never ending affection, love, encouragement and pray of day and night throughout this Final Year Project.

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ABSTRACT

This project is about the study of effect of dimension on stretchable conductive ink electrical conductivity. The parameter use in this project is the different length, different width and different thickness. This paper presents the result on the different dimension effect on the electrical conductivity and the analysis of the microstructure surface. The ink was printed on the TPU substrate which is the substrate can be stretch. After print the ink on the TPU the stretchable conductive ink was cure in an oven at 120℃ with different time of curing, 15 minutes, 30 minutes and 45 minutes. The lower resistance for the length is 40 mm at 45 minutes curing time, the resistance is 1019.79 (R/sq). The result for the width is 7 mm at 45 minutes of curing time, the resistance is 679.86 (R/sq). The lower resistances for the thickness is 0.6 mm at 45 minutes of the curing time, the resistance is 566.55 (R/sq). The effect on the dimension that can be concluding the longer the length of the conductive ink, the higher the resistance it will give. For the thickness, the thicker the conductive ink, the lower the resistance it will show. Lastly, the wider the width of the conductive ink, the lower the resistance of the conductive ink. The curing time also effect the resistance of the conductive ink, the longer the curing time, the lower the resistance, this is due to the decreasing of the gap between the particles on the ink.

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ABSTRAK

Projek ini adalah mengenai kajian kesan dimensi pada konduktif elektrik dakwat konduktif yang boleh diperbaharui. Parameter yang digunakan dalam projek ini adalah panjang yang berbeza, lebar yang berlainan dan ketebalan yang berlainan. Makalah ini membentangkan hasilnya pada kesan dimensi yang berbeza pada kekonduksian elektrik dan analisis permukaan mikrostruktur. Dakwat dicetak pada substrat TPU yang substrat boleh meregangkan. Selepas mencetak dakwat pada TPU, dakwat konduktif yang disegangkan adalah menyembuhkan dalam ketuhar pada 120 ℃ dengan masa pengawetan yang berlainan, 15 minit, 30 minit dan 45 minit. Rintangan yang lebih rendah untuk panjang ialah 40 mm pada masa pengawetan 45 minit, rintangan ialah 1019.79 (R / persegi). Hasilnya untuk lebar ialah 7 mm pada masa pengawetan 45 minit, rintangan ialah 679.86 (R / persegi). Rintangan yang lebih rendah untuk ketebalan ialah 0.6 mm pada 45 minit masa pengawetan, rintangan ialah 566.55 (R / persegi). Kesan pada dimensi yang boleh menyimpulkan panjang dakwat konduktif, semakin tinggi rintangan yang akan diberikannya. Untuk ketebalan, tebal dakwat konduktif, semakin rendah rintangan itu akan ditunjukkan. Terakhir, lebar lebar dakwat konduktif, semakin rendah rintangan dakwat konduktif. Waktu pengawetan juga memberi kesan terhadap ketahanan dakwat konduktif, semakin lama masa pengawetan, semakin rendah rintangan, ini disebabkan oleh penurunan jurang antara zarah pada tinta.

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LIST OF ABBREVIATION

CNT	Carbon Nanotubes
PET	Polyethylene Terephthalate
TPU	Thermoplastic polyurethanes
UTeM	Universiti Teknikal Malaysia Melaka

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CHAPTER 1

INTRODUCTION

1.0 PROJECT BACKGROUND

Nowadays, the conductive ink has a high demand among the industry. Conductive ink is a type of colloid formed by diffusion of the conductive phase in a solvent that can be form in electronic devices. Thus, the classic technology only used in printing technique and lead to many unique advantages such as being low-cost, eco-friendly and energy efficiency. Furthermore, the conductive ink has many potential for other application such as solar cells, thin film transistor and adjustable electronic devices. (Liu et al., 2018)

Electric Paint is a nontoxic, water based, water soluble, electrically conductive paint. It can be used in circuits as a painted resistor element, a capacitive electrode or can function as a conductor in designs that can tolerate high resistivity. It is intended for applications with circuits using low Direct Current (DC) voltages at low currents. Electric Paint adheres to a wide variety of substrates and can be applied using screening printing equipment. Its major benefits include low cost, solubility in water and good screen life. It is black in color and can be over-painted with any material compatible with a water-based paint. (Bare Conductive Ltd, 2016)

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Polyethylene terephthalate (PET) was use in this project as a film for the stretchable conductive ink. The PET nowdays broadly used as a electronic equipment, packaging materials and automotive products. Moreover, the Polyethylene terephthalate had a good properties and therefore it suitable for the stretchable conductive ink.

Furthermore, the Polyethylene terephthalate are good in tensile, impact strength and clarity. So that, the stretchable conductive ink can stretch widely and can use for flexible ectronic product. The PET is a non-biodegradable plastic but its are easily to recycle. (Zander et.al., 2018)

1.1 PROBLEM STATEMENT

The effectiveness of the conductivity of the conductive ink is the bigger issue that the electronic industries have to face. The dimension of the conductive ink effect the effectiveness of the conductive ink. So that, the different thickness, length and the width will affect the conductivity of the stretchable conductive ink.

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1.2 OBJECTIVE

The objectives of this project as follow:

1. To fabricate the stretchable conductive ink on the TPU substrate
2. To evaluate the effect of stretchable conductive ink in length, thickness and the width on electrical conductivity.

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1.3 SCOPE

The scopes of this project are as follow:

1. Fabricate the stretchable conductive ink on the TPU substrate, print the ink using bare conductive ink on the thermoplastic urethane, which is the TPU is a flexible substrate.
2. Measure the conductivity of the conductive ink on three parameter the length, thickness and width using the four-point probe
3. Analyze the surface microstructure of the conductive ink using the microscope.

1.4 GENERAL METHODOLOGY

The details methodology was discuss to complete and to achieve the objective of this project. The step of the general methodology is shown below.

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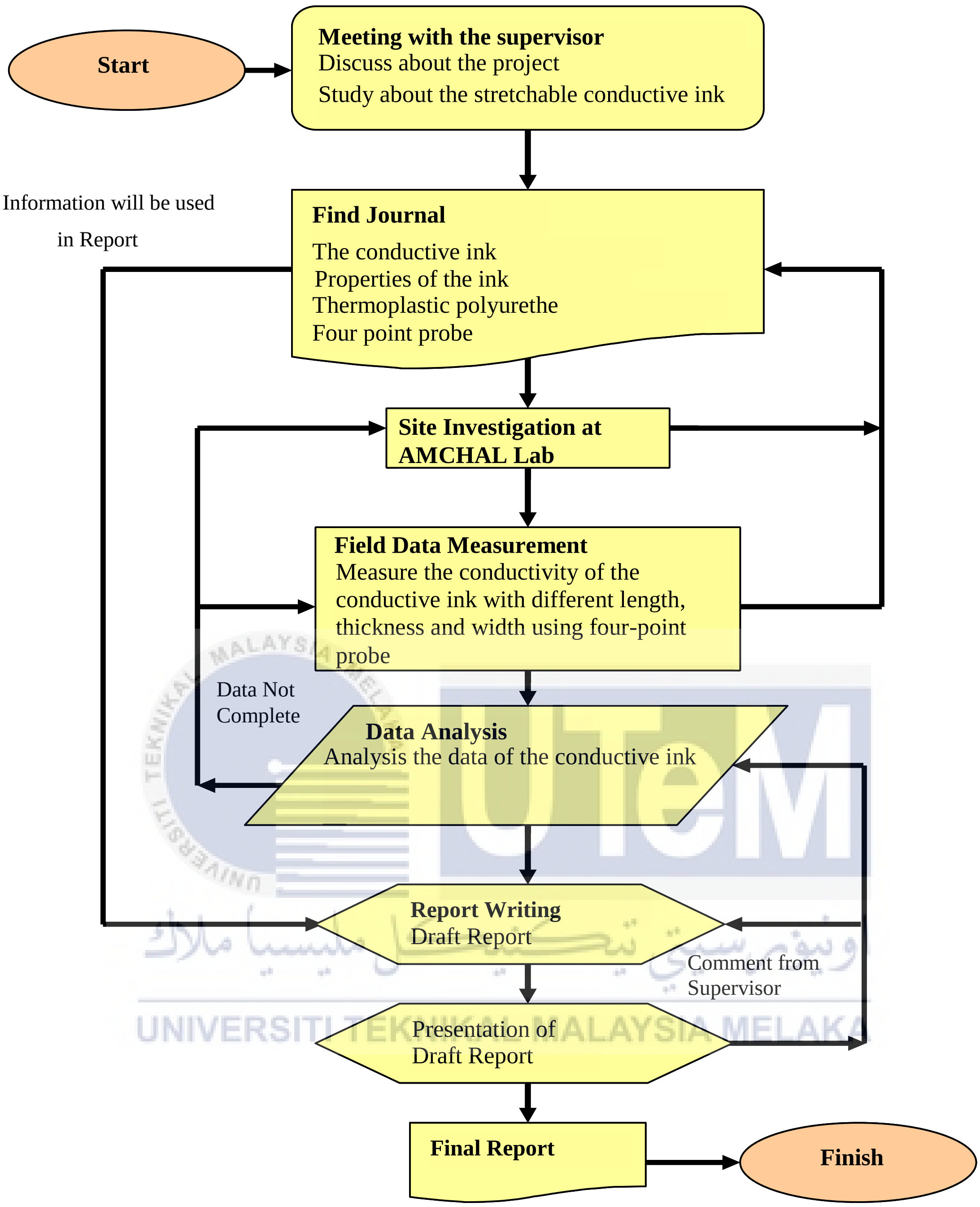

Figure 1.1: Flow Chart for the Project

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CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Conductive inks, which are a type of colloid formed by dispersion of the conductive phase in a solvent, may be printed directly on substrates to form conductive circuits or electronic devices. (Liu et.al., 2018) Graphene inks have recently enabled the dramatic improvement of printed flexible electronics due to their low cost, ease of processability, higher conductivity and flexibility. (Tran et.al., 2018)The ability to control the dispersion of silver particles and concomitantly formulate conductive inks with controlled surface tension, contact angle, and viscosity are critically important. (Yeop & Lewis, 2014)

Carbon nanotubes (CNTs) suitable use for replacing many existing materials, such as, electrical properties, superior thermal and mechanicals .The advantages of this materials was improves the fracture interfacial rigidity and can stop micro-cracks evolution. (L. Guadagnoet.al., 2018)

CNT is the composites where can be change to others material cause of the thermal, mechanical and electronic properties. Then, the diffusion of a small amount of CNTs in polymer composites changes the structure stiffness. In addition, the growth of polymer polymer-based composites with specific functionalities and performance to fulfill industrial requirements still presents several critical issues. Thus, CNT commonly tend to form collection and reduce performance in normal properties. (Guadagno et. al., 2018)

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The adhesively bonded joint has given the solutions for other mechanical joints in load-bearing structures such as automotive or other engineering application. Then, it can give many advantages such as low cost and lower weight making the structures able the aviation environmental impact. A significant progress in the field of structural joints is the replacement of traditional rivets with structural epoxy conductive adhesives. (Vertuccio et. al, 2017)

2.2 CONDUCTIVE INK

The stretchable printed circuit well known in conductive ink. The conductive can be define as the electrical view in the ability of the material substances to conduct electricity. The high conductivity of the materials such as metal, the electric current will able to flow easily when voltage is exerted. It also has stated that the material with lower resistance will conduct electricity more efficiently compared to material that has higher resistances. (Banfield, 2000)

Furthermore, the electrical resistivity has a specific electrical resistance is a parameter to measure how potentially conductors to resists the flow of electric current. Then, the conductivity is inversely proportional to the resistivity where the high conductivity of material results of a lower resistivity. (Merilampi et. al., 2009)

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In addition, the conductive ink that has printed on the substrate which give a functional of conduction that the ability of the electrical charge carries electrons. Usually, the conductive elements used in electronic applications to provide stable electrical connection. The conductive ink layer has been built up or has been printed on a polymer of the substrate to form the flexible printed circuit. (Liu et. al., 2018)

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Thus, polymer substrates is one of the polymer-based electrically conductive inks and widely in electrical industries. (Banfield, 2000). It is used to make the conductive paths on the substrate. There are several types of substrate that are able to be used as polymer-based electrically such as Thermoplastic Polyurethane (TPU), which has mentioned details in the subtopic below.

There are several parameters that can affected the performance of sheet resistance, Rs (Ω/sq) of the film which includes of forces applied (tension) and temperature applied to the film. The temperature has applied will influence the particle radius of the conductive filler more precise and will affect the electrical conductivity of the conductive ink. Furthermore, the percentage of tension applied to the conductive ink also will affected the sheet resistances due there will be changes on the gap between particles in the conductive filler. Lastly, the sheet resistances is measured by using Four-Point Probe. (Tran et. al., 2018)

2.2.1 Preparation of Conductive Ink

In combination, 5 g of $CuSO_4$ and 1 g of sodium oleate were broken down in 50 mL of deionized water. Accordingly, 100 mL of xylene was filled the above arrangement, and the blend experienced unconstrained partition into two layers, the upper of which was xylene. In mixing, the blend was converted into a consistently conveyed homogenous stage, into which 15 mL of hydrazine hydrate was quickly infused. Ten minutes later, the response framework turned ruddy darker. The blend was permitted to remain until the point that it layered with the Cu NPs in the upper xylene layer. (Liu et.al., 2018)

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Graphene can be obtained using two distinct strategies, the bottom-up and the top-down. the top-down approaches involve the production of graphene from existing bulk carbon sources, by either exfoliation of graphite towards graphene, reduction of graphene oxide or carbonization of other materials. These methods are widely used for its numerous advantages in term of high yield, low cost, and solution processability, however the quality of graphene produced is of concern. (Tran et.al., 2018)

2.3 PROPERTIES OF FILLER

In the developing countries, it is important to produce product with higher efficiency, high sustainability and affordable. Thus, important features need to be considered in order to enhance the properties of the product. For this study, it is related to the stretchable printed circuit. There are several important features must be review in order to the stretchable printed circuit. The features includes the low manufacturing costs, high durability and high efficiency. In order to meet the requirement of the features, it is necessary to choose high quality of the materials. High quality of material is strongly related to the several properties for example mechanical and electrical properties. Mechanical properties includes of elasticity and tensile strength while electrical properties can be known as sheet resistances and thermal conductivity. Conductive filler is one of the main components in the stretchable printed circuit. Conductive filler provide electrical conductivity to the circuits and form of conductive ink when it combining with the binder and solvent. (Merilampi et. al., 2009)

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2.3.1 Carbon Black

Carbon black is popular carbon based filler and has been widely used and it can be present as the conductive filler which has good in electrical properties and light in weight (Han & Fina, 2011) Then, carbon black is not only good in electrical properties because of it has low resistivity (55 Ω/sq) which has stated at the figure 2.1 below. Then, it became popular in electronic manufacturer due to the carbon black has low cost materials. The electrical conductivity has been improved day by day. (Pu et. al., 2014)

Table 2.1: Properties of Carbon Black

TEST	PROPERTIES
Sheet Resistance at 50 micron film thickness (Ω/sq)	55
Density (g/ml)	1.16
Viscoscity	Thixotropic
Thinner	Water

(Bare Conductive, 2016)

Furthermore, the good electrical conductivity can be formed if the carbon black has produced high conductivity and having a very high surface area. (Nanda, 2008) Then, the electrical conductivity of the Carbon Black is 55 Ω/sq. (Bare Conductive Ltd, 2016) For example, the carbon nanotubes produces higher temperature when it apply to carbon. Thus, it will give lower sheet resistivity value since the gap between particle in the conductive ink decrease. (Hasnanoui et. al., 2017) In a certain condition when heat has applied to the carbon black, the particle of conductive filler expand and reduce the gap between fillers. Thus, the electron will flow easily due to the conductive filler has more contact area between others. Besides, it has increase the conductivity of conductive ink. (Banfield, 2000).

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The Bare Conductive by referring the figure 2.2 has made a research about the relationship between the length and the resistance. The company had been approved that the longer the length of the conductive ink, the higher the resistance. The results has been proved by results in resistance and length has shown in figure 2.2 where the shortest length for 70 mm x 3 mm gives the resistance 473 Ω. Then, the longest length for 130 mm x 3 mm gives the resistance 869 Ω

Generally, the carbon black provide the best electrical conductivity instead and the carbon black also in a low cost. Hence, this is the one of the reasons for choosing these materials as conductive filler in this study.

Figure 2.1: The results of the dimension from the Bare conductive LTD
(Bare Conductive, 2016)

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2.3.2 Silver

Recently silver inks have been used in novel applications, for example in RFID tags. Conductive metallic inks are widely used in printed electronics, such as photovoltaics, displays, batteries, sensors, and biomedical devices, while the silver ink or these applications representing over 90% of the materials used in a $1.5B annual market. Hence, the ability to control the dispersion of silver particles and concomitantly formulate conductive inks with controlled surface tension, contact angle, and viscosity are critically important. (Merilampi et.al., 2009) Next, the electrical conductivity of the Silver is 51 Ω/sq. (Logeeswaran et. al., 2008)

2.3.3 Carbon Nanotubes (CNT)

In year 1991, the polymers has been discovered which Carbon Nanotubes. It usually in the formed of the long and thin cylinders of carbon. These are large macromolecules that are unique for their size, shape, and remarkable physical properties. Currently, the physical properties are still being discovered and disputed. Nanotubes have a very large range of electronic, thermal, and structural properties that change depending on the different kinds of nanotube (defined by its diameter, length, and chirality, or twist) (Merlini et. al, 2018)

2.3.3.1 Carbon Nanotubes (CNT) Properties

The size of manufactured nanotubes typically varies widely. For commercial use, nanotube manufacturers will need to make size more consistent. Though nanotubes are very narrow, nanotube matrices typically have quite large (100nm) spacing between tubes. (Merilampi et.al., 2009)

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In addition, some of the properties such as electrical conductivity, thermal conductivity with expansion, heat conductivity, and mechanical properties. Thus, the pure carbon polymers it can be manipulated using the common and rich chemistry of that element. (Merlini et. al, 2018) The properties for the thermal conductivity and expansion which CNTs which superconductivity below 20 K and it can be approximately −253 ºC due to the strong in-plane C–C bonds of graphene. (Merilampi et.al., 2009). Then, the electrical conductivity of the CNT is 160 Ω/sq. (Hua et. al., 2017)

According to the Guadagno et al., (2018) thickness is about 50 µm and a surface resistivity of 0.001 Ω·cm. Then, the last approach to focus on non-oxidized grapheme flakes with non-covalent functionalization of 1-pyrenebutyric acid in nano-composites able to manifest outstanding thermal conductivity (~1.53 W/mK) and improved mechanical properties (~1.03 GPa) (Song et. al., 2013)

The next properties which electrical conductivity where the structure of atoms in a carbon nanotube reduce the collapse between the electrons particle and atoms, a carbon nanotube is highly conductive. The strong bonds between carbon atoms also allow carbon nanotubes to withstand higher electric currents than copper. Electron transport occurs only along the axis of the tube. (Merlini et. al, 2018)

Based on the table 2.2 below has shown the comparison between the electrical conductivity in the Ω/sq unit.

Table 2.2: Electrical Conductivity

Material	Electrical Conductivity (Ω/sq)
Carbon Black	55
Silver	51
Carbon Nanotubes	160

(Sources: Logeeswaran et. al., 2008)

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2.4 SUBSTRATE

2.4.1 Thermoplastic Polyurethane (TPU)

TPU is a linear, block copolymer consisting of alternating sequences of hard and soft segments. (Ghariniyat & Leung, 2018). Thermoplastic polyurethanes (TPUs) have a place with the gathering of thermoplastic elastomers that offer the mechanical properties of rubbers with the processability of thermoplastic polymers, making them recyclable. (Theiler et.al., 2018)

Thermoplastic polyurethane (TPU) is one of the polymers that have great flexibility and processibility. (Choi et.al., 2017). Thermoplastic polyurethane (TPU), a kind of thermoplastics with the mechanical performance characteristics of rubber, is described as "bridging the gap between rubber and plastics. (Zhang et.al.,2016)

TPU materials consist of thermoplastic hard segments and elastomeric soft segments, which are linked by hydrogen bonds. (Theiler et.al., 2018)The polyester, polyethylene and polypropylene are used as a plastics base materials for conductive ink film. (Kinya Shiraishi et.al, 2011)The material used was a polycaprolactonecopolyester based on thermoplastic polyurethane (translucent and colorless pellets). (Banfield, 2000)

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2.4.1.1 Thermoplastic Polyurethane (TPU) Properties

TPU foam was the most promising one due to its high cell population density and small cell size. (Ghariniyat & Leung, 2018). Based on table 2.3 has shown the physical properties of TPU :

Table 2.3: The physical properties of TPU

Properties	Value
Density	1060 $kg.m^{-3}$
Melting Temperature	171 – 181 ℃
Softening Temperature	75.6 ℃
Shore Hardness	72 A

(Source: Ghariniyat & Leung, 2018)

Polyurethane block copolymers generally contain a high degree of hydrogen bonds. (Ghariniyat & Leung, 2018). Due to cross linking, the stiffness of the material increases, drastically reducing the friction coefficient of unfilled TPUs. (Theiler et.al., 2018)

Thermoplastic has high elasticity combined with high abrasion resistance.It shows that the tensile strength of TPU/CF was decreased when the fiber content is less than 10 wt% but when the fiber content more than 10 wt% the tensile strength was increased. The MDI modification make the tensile strength, tensile modulus, elongation at break, and toughness of composite more improved compared to TPU/CF composite. (Zhang et.al.,2016)

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2.4.2 Polyethylene Terephthalate (PET)

Polyethylene terephthalate (PET) as known as polyester which a long-chain semi-crystalline thermoplastic polymer where it has biggest produced. In year 2009, the total production of semi-crystalline thermoplastic polymer about 31.929 (Oerlikon , 2010)Thus, the PET fibers are usually used as a synthetic fibers. (Tomisawa et al., 2017) Furthermore, the PET is possesses in a good mechanical and thermal properties, low permeability, good transparency and chemical resistance conductivity (Thongsong et. al., 2017) Due to its mechanical properties, ability to be recycled, low cost and easy in the production line, PET fibres are mostly used in many textiles and technical applications (Broda et. al., 2007), (Gashti et. al., 2012), (Zeng et. al., 2012)

Generally, it commonly used in industry, improvements in their strength are desirable. There have been a many number of studies of the relationship between the structure and properties of PET fibers and mostly focusing on improvement of their strength. (Tomisawa et al., 2017) For example, the deterioration of mechanical properties of diamond takes place at temperatures of 800–1000 K as a result of oxidation and graphitization processes. (Kondrina et. al.,2018)

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Polyethylene Terephthalate (PET) were cut into small pieces, then loaded into titanium capsules 6mm in diameter and 3.7 mm in height with wall thickness of 0.3 mm.(Kondrina et. al.,2018) Then, the tensile results show that the elongation to failure was similar to an injection molded part (3.5%) and tensile strength of 35.1 ± 8 MPa was comparable to commercial polycarbonate ABS filament, demonstrating the robustness of the material. (Zander et. al., 2018) However, the poor dispersion and agglomerates create voids and cracks in the polymer matrix that can result in reduced material properties and an ununiformed morphological structure (Broda et. al., 2007) (Kusuktham et. al., 2012)

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2.4.2.1 Polyethylene Terephthalate (PET) Properties

In addition, there are many studies have investigated factors that influence the material properties of additive-polymer products. The study has found that interfacial bonding between the additive and polymer matrix and the dispersion of the additive in the matrix are the main determinants of properties of the end products. (Zeng et. al., 2012) (Park et. al., 2010)

These factors depend on the characteristics of the additives, like size distribution, shape and loading. Then, the smaller can give the better tensile properties compare to the larger particles exhibited poor material properties (Deshmurk et. al., 2010) (Arencón et. al., 2009) The data has obtained in the report where it has effects on tensile properties like tensile strength, Young's modulus, flexural strength and elongation at break (Bhowmik et. al., 2008) (Gashti et. al., 2012) (Deshmurk et. al., 2010)

According to the mechanical properties, the PET consists of bulk strengths between 30 and 100 MPa and elastic moduli on the order of 1.3–3.6 GPa. Then, the printed parts has lower the strengths due to voids and weak interlayer adhesion. However, most of the polymers used such as polypropylene have bulk strengths below the aforementioned range, polyethylene terephthalate (PET) has an average strength and modulus of 70 MPa and 3.1 GPa, respectively. (Zander et. al., 2018)

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2.4.3 Comparison between PET and TPU

The table 2.4 below shows the comparison between Thermoplastic polyurethanes (TPU) and Polyethylene Terephthalate (PET).

Table 2.4: Comparison between PET and TPU

Properties	TPU	PET
Tensile strengths	20.7 – 96.0 MPa	30 - 100 MPa
Modulus of Elasticity	0.483- 5.50 GPa	1.3–3.6 GPa
Strength	52.4 – 79.3 MPa	70 MPa
Stretchable	Yes	No

(Sources: Zander et. al., 2018)

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CHAPTER 3

METHODOLOGY

3.0 INTRODUCTION

This chapter explained on the flow, procedures and the method use in this project from the beginning until the end of the project. Besides that, using flow chart will show the step and the flow of this project. This chapter will also explained on how the conductive ink was prepared and which equipment was selected to run this project, which is the effect of stretchable conductive ink dimension on electrical conductivity.

3.1 PROJECT PLANNING

This section will show on how this project was carried out to ensure that this project will be conduct smoothly and make this project conduct according in time. First of all the objective and scopes must be clearly understand to handle this project. Then, the parameter was identified which is the conductive ink, the thermoplastic polyurethane and the equipment to handle this project. According to the parameter, the literature review has been done in chapter 2 as stated before and the process and step of this project has been mentioned in the figure 3.1 below.

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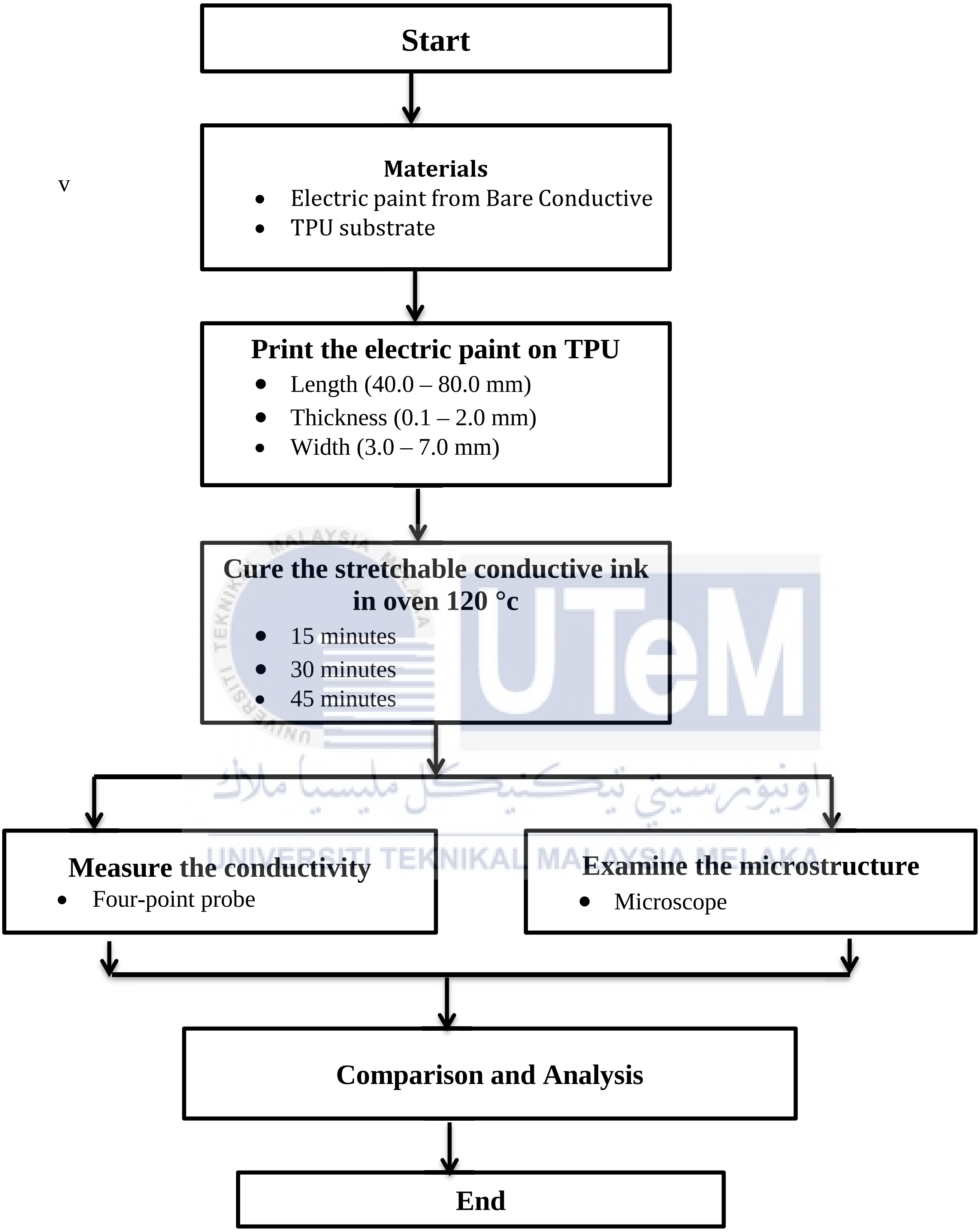

Figure 3.1: Flow chart of the project

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3.2 MATERIALS

3.2.1 Conductive Ink

The material of the conductive ink use in this project is the electric paint from BARE CONDUCTIVE LTD. The figure 3.2 are the example electric paint from Bare Conductive. The electric paint was selected because its has a high sheet resistance, water-soluble and it is a low cost product. The electric paint is a nontoxic, water based, water soluble, electrically conductive paint, intended for applications with circuits using low DC voltages at low currents. The chemical name for this electric paint is water-based dispersion of carbon pigment in natural resin. The viscosity of the materials is highly viscous and shear sensitive, the density is 1.16 g/ml and it has a 55Ω/sq at 50-micron film thickness for the sheet resistance. The curing time for the electric paint is 15 minutes and the temperature should at room temperature.

The power sources for the electric paint at a low current, the power limit is not more than 12VDC. For the substrates, the electric paint will adheres well to metal, plastics, wood and paper conductor. Sometimes, the electric paint cannot adheres well to some type of plastic and glass but this can be improve by roughing the surface of the glass or the plastic to make the electric paint adheres well. The flexibility of the electric paint depends on the layer thickness and the substrate. The thin the layer of the thickness, the most flexible the electric paint. If substrate is stretcher will get the low result but the substrate not stretchy will work better. The typical circuit line width is 0.5 – 10 mm and figure 3.3 is the resistance sample visual at the diagram below.

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Figure 3.2: The electric paint from Bare Conductive

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3.3 EXPERIMENT SETUP

3.3.1 Print Stretchable Conductive Ink on TPU

The electric paint will print on the TPU. The example of TPU in the figure 3.3 Cut the TPU into small pieces and take the scotch tape and place in on the TPU as the thickness of the conductive ink. After that, take the electric paint using the plastic spoon and place it on the TPU. Take a razor blade and apply it on the TPU. In the figure 3.4 is a example of razor blade. The length of the conductive ink has been decided. Make a different length for the conductive ink so that, it can be determining which length has better conductivity.

Figure 3.3: The example of TPU

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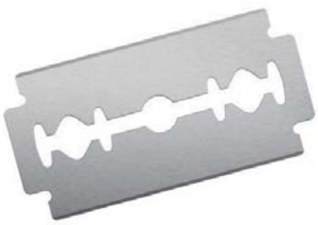

Figure 3.4: The example of razor blade

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After finished the printing section, the stretchable conductive ink will place into the oven for the curing time. The curing time is to make sure that the electric paint will adhesive to the TPU strongly. The temperature for the curing time in the oven is 120 ℃ for 15 minutes 30 minutes and 45 minutes in the oven. Figure 3.5 are the example of the oven to be place the stretchable conductive ink for the curing time. The figure 3.6 shows the procedure for print the ink on the TPU substrate. The figure 3.7 and 3.8 is the results for the conductive ink before and after the heating process.

Figure 3.5: The oven for curing

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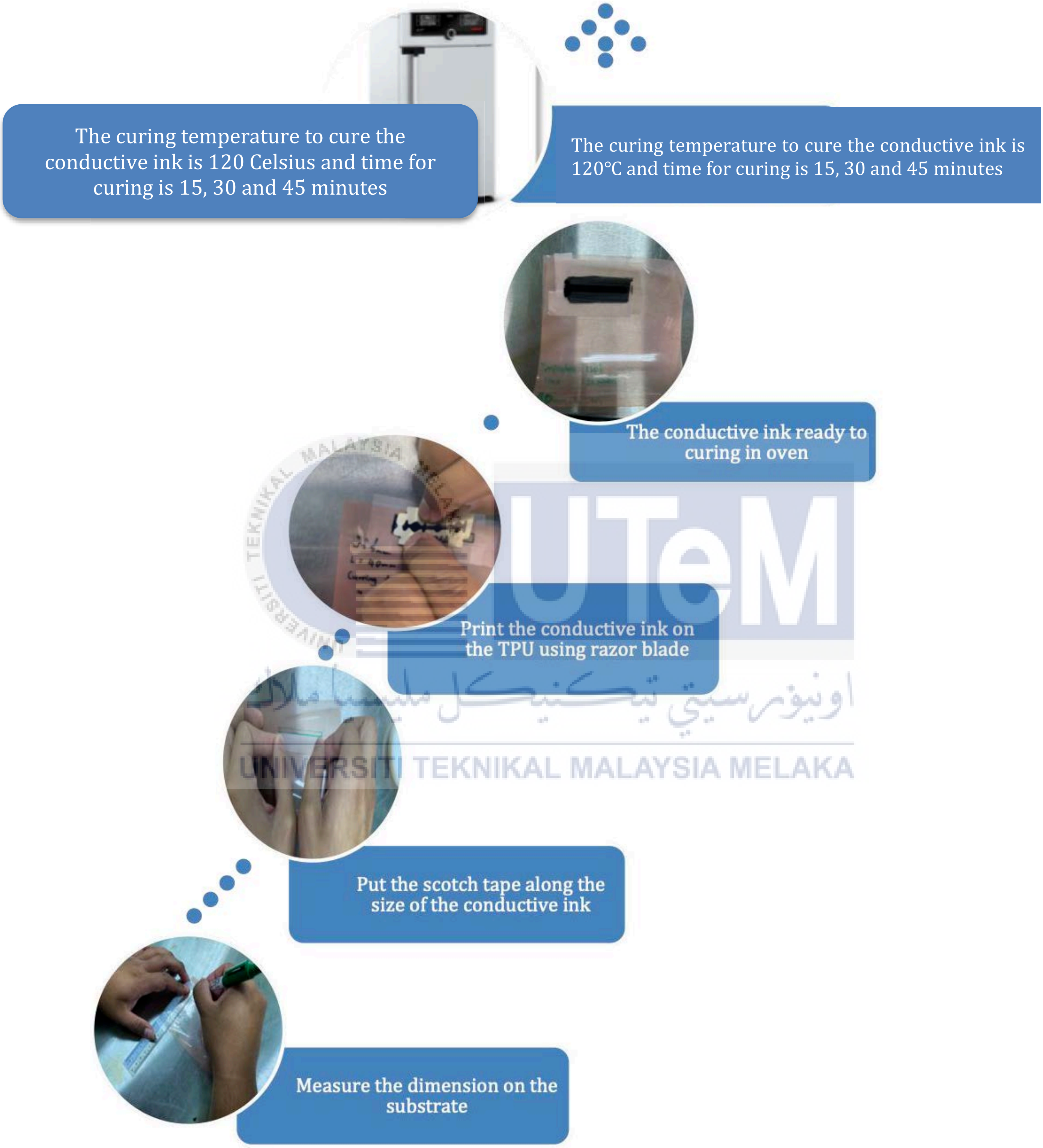

Figure 3.6 : The procedure print the ink on TPU substrate

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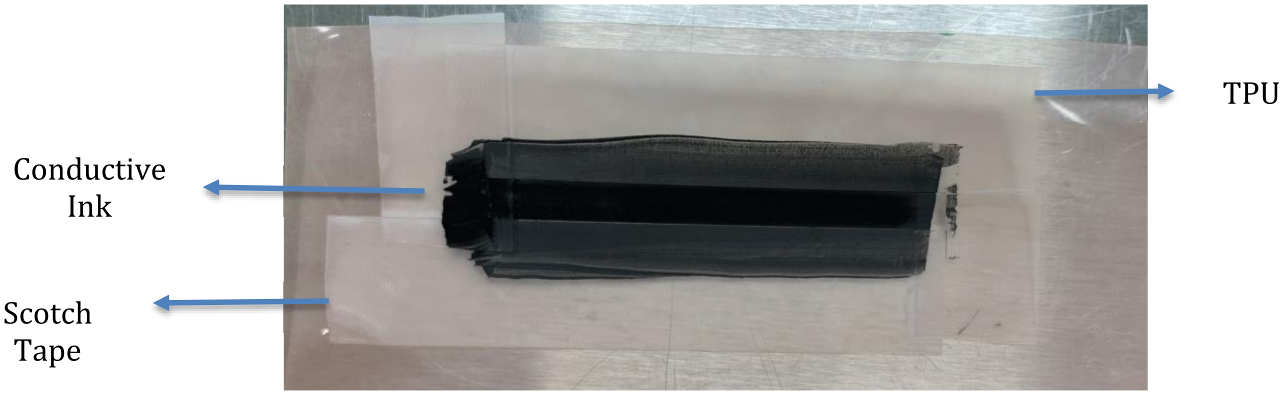

Figure 3.7 : The conductive ink before curing in the oven

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Figure 3.8 : The conductive ink after curing in the oven

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3.3.2 Prepare Sample of the Conductive Ink

There are different dimension to measure the conductivity. The different dimension includes the length of the stretchable conductive ink. In this project, to evaluate that which dimension is the better conductivity, the longer the length the high the conductivity or the shorter the length the high the conductivity. Moreover, not only the length but the thickness and the width are including with different dimension to evaluate the conductivity. So that, we can conclude that the dimension of the stretchable conductive ink are influence or not influence the conductivity. In the table 3.1 show how the ink was measure as length, width and thickness and figure 3.9 below has shown example dimension of the ink on substrate.

The table 3.1: The Different dimension.

Condition	Dimension		
Length	L1 (40 mm)	L2 (60 mm)	L3 (80 mm)
Thickness	T1 (0.2 mm)	T2 (0.4 mm)	T3 (0.6 mm)
Width	W1 (3 mm)	W2 (5 mm)	W3 (7 mm)

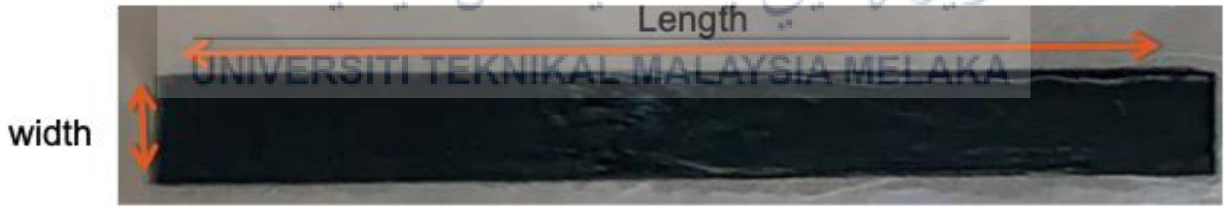

Figure 3.9 : Example dimension of the ink on substrate

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3.3.3 Measure the Conductivity of The Conductive Ink Using Four-Point Probe

After the curing time for the stretchable conductive ink finished, the conductivity of the sample is measure using four-point probe. Four-point probe are used for determine semiconductor characterization, but its usually used to measure the sheet resistance of thin layer. So that, this equipment are suitable for this project because its can measure the conductivity on a stretchable conductive ink. The four-point probe also can give the accurate result for the resistance. In the four probe method, contact and spreading resistances are very low with voltage probes and hence accuracy in measurement is usually very high. To measure very low resistance values, four-probe method is used. The resistance of probe will be not be added to that of sample being tested. It uses two wires to inject current in the resistance and another two wires to measure the drop against the resistance. The schematic for four-point probe in figure 3.10 are show how the four-point probe can read the resistivity on a thin layer.

Figure 3.10: The four-point probe

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The limitation of the four-point probe is the material must be contact to the probe to make ohm and to achieve the reading on the display, the current source required to the maximum because of the very low resistive material. The best current through the probe is to 10 mA because of the heating effects and excessive current density at the probe tips. To measure the high sheet resistivity material it must using the low current and avoiding a greater voltage indication than 200 mV. Furthermore, low-level measurement is negatively affected by various sources. An unclean sample or a sample that has surface doping will lead to inaccurate figures due to an impeded ohm contact or current leakage. The figure 3.11 and 3.12 show the four point that measured by the four-point probe and how the ink and substrate was measured.

Figure 3.11 : Four point that measure by the four-point probe

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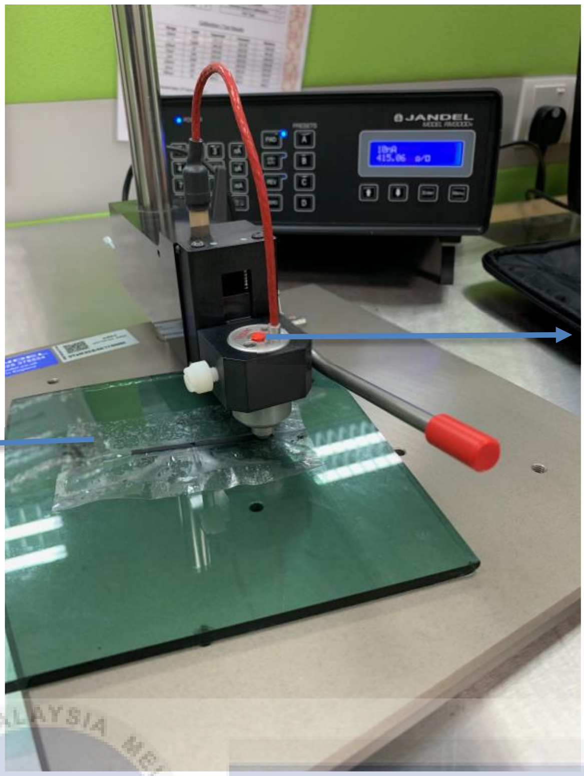

Figure 3.12 : How the ink was measured by four-point probe

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3.4. ANALYZE THE SURFACE MICROSTRUCTURE OF THE STRETCHABLE CONDUCTIVE INK

The microstructure of the stretchable conductive ink must to be examine after the conductivity are measured. It is to examine the microstructure of the sample. The microstructure of the stretchable conductive ink must be not fracture or damage, if the microstructure is damaged or fracture that is means the stretchable conductive ink was not good. The microstructure of the sample must be collide and compact each other to get the high conductivity. To analyze the microstructure of the stretchable conductive ink, the microscope is use in this project.

3.4.1 Microscope

Microscopes are instruments designed to produce magnified visual or photographic images of small objects. The microscope must accomplish three tasks: produce a magnified image of the specimen, separate the details in the image, and render the details visible to the human eye or camera. This group of instruments includes not only multiple-lens designs with objectives and condensers, but also very simple single lens devices that are often hand-held, such as a magnifying glass. In this project, the microscope are used to analyze the surface the microstructure

Figure 3.13 : The microscope

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CHAPTER 4

RESULT AND DISCUSSION

4.0 INTRODUCTION

In this chapter, the result and discussion of the effect dimension on the stretchable conductive ink, the microstructure of the conductive ink, and the influence of curing time for the conductive ink on substrate are discussed wisely. In this experiment, the curing temperature for the ink is 120 ℃ and the time for the curing the ink 15 minutes, 30 minutes and 45 minutes. The parameter for the length, thickness and the width are show in the table 4.1 below.

Table 4.1: The parameter for the experiment

Condition	**Dimension**		
Length	40 mm	60 mm	80 mm
Thickness	0.2 mm	0.4 mm	0.6 mm
Width	3 mm	5 mm	7 mm

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4.1 The effect of the length on the conductive ink

a) Thickness 0.2 mm and width 3 mm

Based on the figure 4.1 has shown below stated that the curing time for 15 minutes (Blue Line), 30 minutes (Red Line), 45 minutes (green line) with the different length (width 3 mm and thickness 0.2 mm). The conductive ink has been curing in a constant temperature (120℃). Next, after the conductive ink has curing then the conductive ink has been test the resistance using Four-Point Probe with the four different points as show in the figure 4.1 below. The result of the points has shown in the Appendix A.

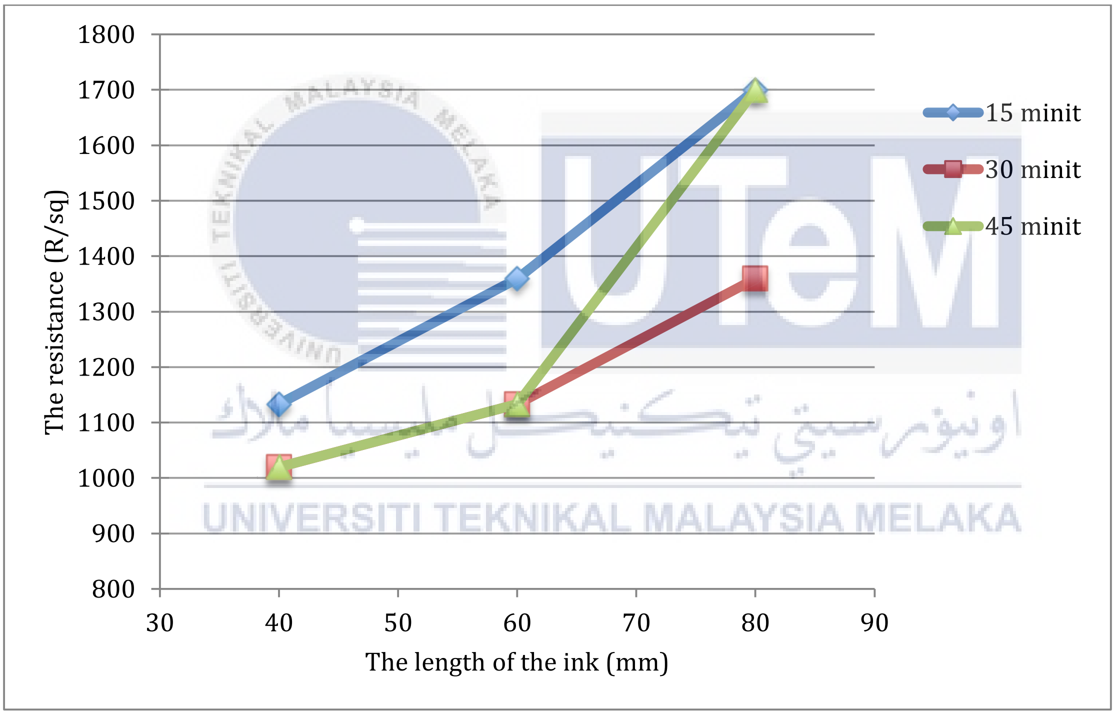

Figure 4.1: The Different length result thickness 0.2 mm and width 3 mm

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The results show the effects of different between length and curing time. The figure 4.1 has shown the curing time for 15 minutes. The average resistance results have been obtained. The length of 40 mm resistance has give the results which is 1133.1 R/sq, meanwhile the length for 60 mm give the results 1359.72 R/sq. Then, the 80 mm give the reading of resistances is 1699.65 R/sq.

The graph also shows the results for 30 minutes and 45 minutes curing time. The results also give the lower resistance at the length 40 mm, which is for the 30 minutes the resistance, is 1019.79 R/sq and for 45 minutes is 1019.79 R/sq. The higher resistance is at the maximum length, which is 80 mm. It is give the resistance for 30 minutes are 1359.72 R/sq and for the 45 minutes is 1699.65 R/sq.

From the graph above in figure 4.1, it can be conclude that the longer the length of the ink, the higher the resistance it will give. The curing time also affect the resistance of the conductive ink. From the pattern of the graph, the result also can be concluding the longer the time of curing time, the lower the resistance in the conductive ink. So that, from the condition 1 the lower resistance at 40 mm length, 0.2 mm thickness and 3 mm width.

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b) Thickness 0.4 mm and width 5 mm

The results below in figure 4.2 show the effects of different between length and curing time. The figure 4.2 has shown the curing time for 15 minutes. The average resistance results have been obtained. The length of 40 mm resistance has give the results which is 1926.27 R/sq, meanwhile the length for 60 mm give the results 2152.89 R/sq. Then, the 80 mm give the reading of resistances is 2606.13 R/sq

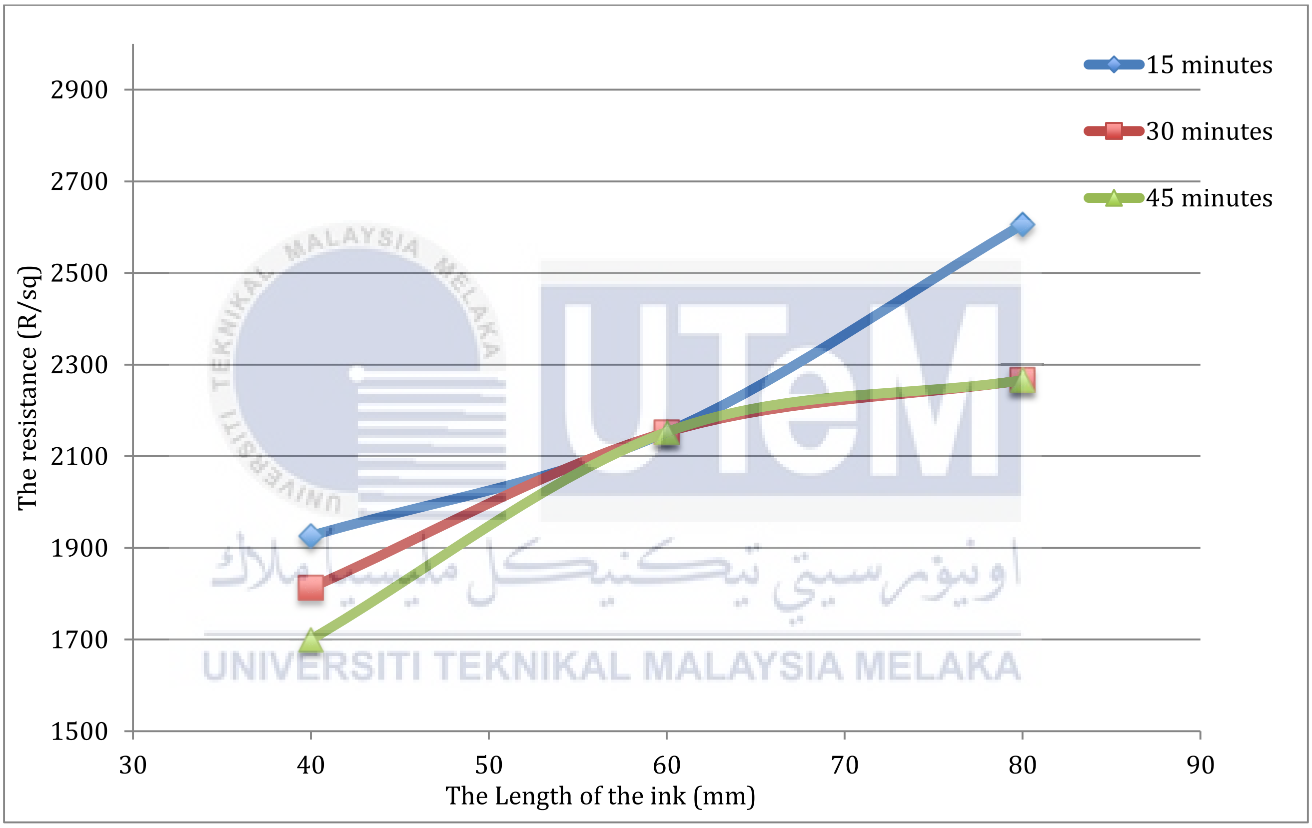

Figure 4.2 : The Different length result thickness 0.4 mm and width 5 mm

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The graph also shows the results for 30 minutes and 45 minutes curing time. The results also give the lower resistance at the length 40 mm, which is for the 30 minutes the resistance, is 1812.96 R/sq and for 45 minutes is 1699.65 R/sq. The higher resistance is at the maximum length, which is 80 mm. It is give the resistance for 30 minutes are 2266.2 R/sq and for the 45 minutes is 2266.2 R/sq.

From the graph, it can be conclude that the longer the length of the ink, the higher the resistance it will give. The curing time also affect the resistance of the conductive ink. From the pattern of the graph, the result also can be concluding the longer the time of curing time, the lower the resistance in the conductive ink. So that, from the condition 2 the lower resistance at 40 mm length, 0.4 mm thickness and 5 mm width.

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c) Thickness 0.6 mm and width 7 mm

The results below in figure 4.3 show the effects of different between length and curing time. The figure 4.3 has shown the curing time for 15 minutes. The average resistance results have been obtained. The length of 40 mm resistance has give the results which is 2152.89 R/sq, meanwhile the length for 60 mm give the results 2379.51 R/sq. Then, the 80 mm give the reading of resistances is 2492.82 R/sq. So that, the 80 mm length give the higher resistance at the 15 minutes curing time.

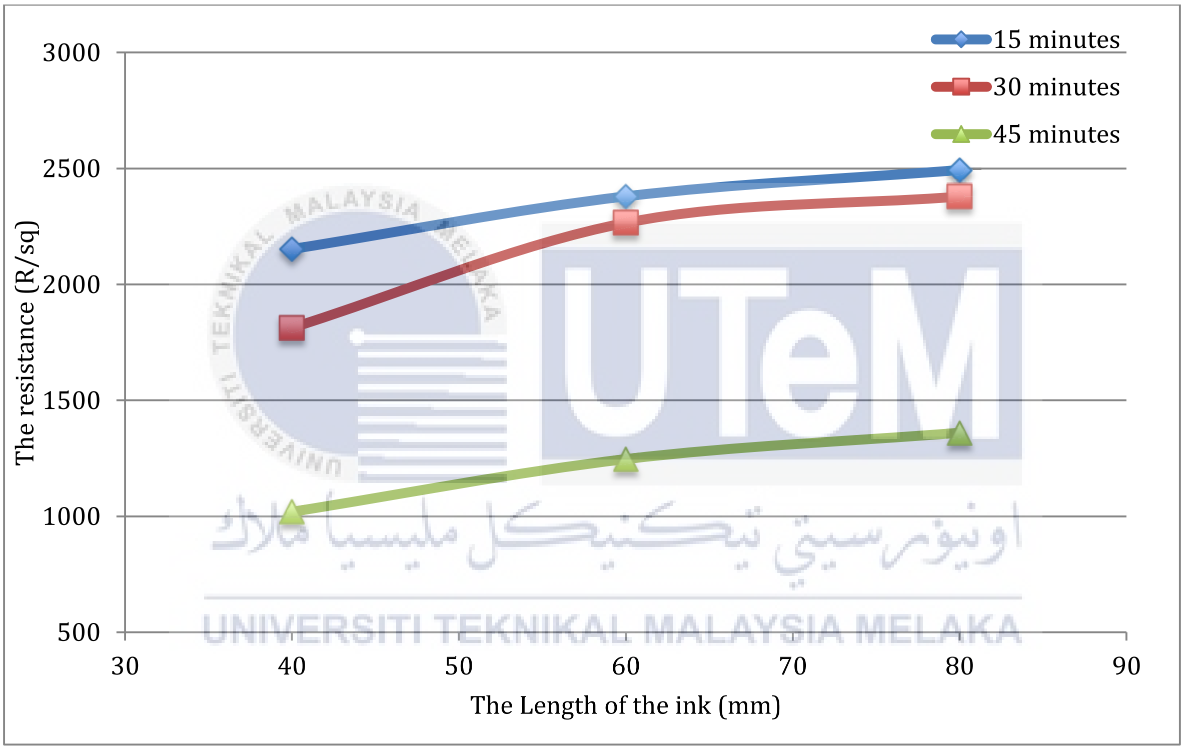

Figure 4.3 : The Different length result thickness 0.6 mm and width 7 mm

The graph also shows the results for 30 minutes and 45 minutes curing time. The results also give the lower resistance at the length 40 mm, which is for the 30 minutes the resistance, is 1812.96 R/sq and for 45 minutes is 1019.79 R/sq. The higher resistance is at the maximum length, which is 80 mm. It is give the resistance for 30 minutes are 2379.51 R/sq and for the 45 minutes is 1359.72 R/sq.

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From the graph in figure 4.3 above, it can be conclude that the longer the length of the ink, the higher the resistance it will give. The curing time also affect the resistance of the conductive ink. From the pattern of the graph, the result also can be concluding the longer the time of curing time, the lower the resistance in the conductive ink. So that, from the condition 3 the lower resistance at 40 mm length, 0.6 mm thickness and 7 mm width.

The ink has a lower resistance because after the ink was curing in the oven the particle in the ink will expand and reduce the gap between the filler. This make the electron will flow easily to flow and had a low resistance (Banfield, 2000). For the length the shorter length has a lower resistance because the electron are easily to flow in a short length than a longer length. This is because the longer dimension has several obstacles that the electron had to flow and make the resistance has a higher value. Thus, the results for this project have been proved by the Bare Conductive where has stated the longer the length, the higher the resistances and vice versa. (Bare Conductive, 2016)

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4.2 The effect of width on the conductive ink

a) Thickness 0.2 mm and length 40 mm

The graph in figure 4.4 below shows the result for the effect of width on the conductive ink. The graph also shows the difference result for 3 different curing times, which is 15 minutes (blue line), 30 minutes (red line) and 45 minutes (green line). The result for 15 minutes (blue line) shows that, the width of 3 mm give a results 2039.58 R/sq, meanwhile the width of 5 mm give the average resistance is 1812.96 R/sq. The width of 7 mm gives the lower result among the width in 15 minutes of curing time, 1699.65 R/sq. So that, the higher result for the resistance is 3 mm of width. The better average of resistance is lower, then, the width of 7 mm gives the lower average of resistance.

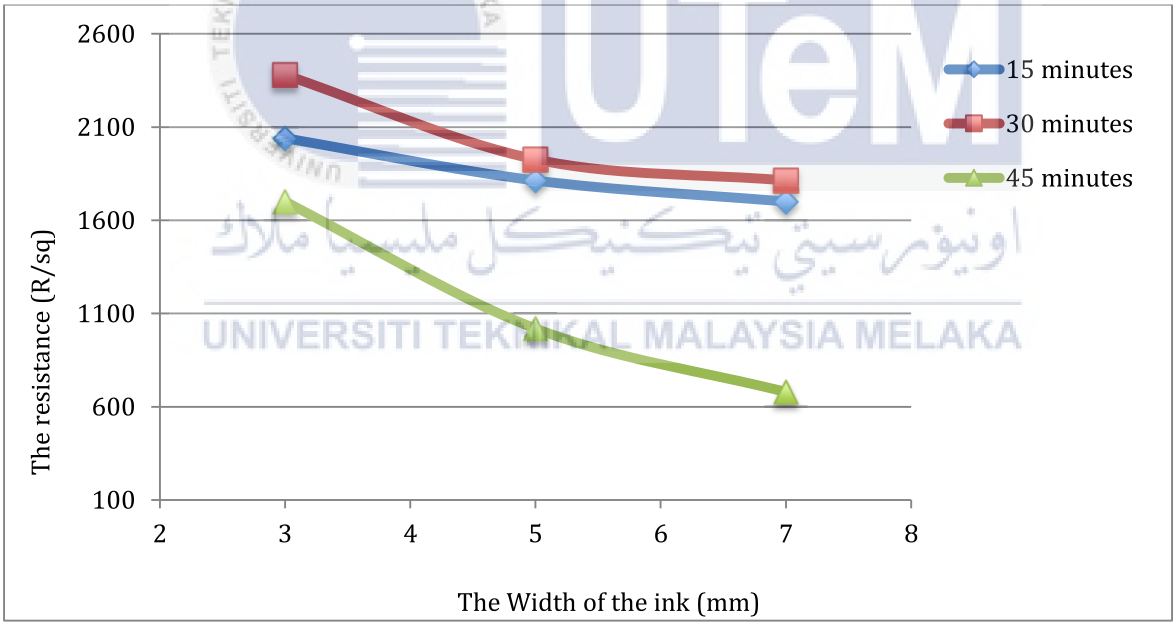

Figure 4.4 : The Different Width result thickness 0.2 mm and length 40 mm

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The graph also shows the result for the 30 minutes and 45 minutes of curing time with different width. The results give the higher result at 3 mm width for 30 minutes of curing time, the average resistance is 2379.51 R/sq and for the 45 minutes is 1699.84 R/sq. The result give the lower resistance at 7 mm width for both curing time 30 minutes and 45 minutes, 1812.96 R/sq and 679.86 R/sq. From the pattern graph above, it can be conclude that the bigger the width of the ink, the lower the resistance it will give.

Furthermore, the curing time also affect the average of the resistance. From the graph, it shows that the 45 minutes (green line) curing time at the bottom. So that it can be conclude, the longer the curing time, the lower the average resistance will get.

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b) Thickness 0.4 mm and length 60 mm

The graph below in figure 4.5 shows the result for the effect of width on the conductive ink. The graph also shows the difference result for 3 different curing times, which is 15 minutes (blue line), 30 minutes (red line) and 45 minutes (green line). The result for 15 minutes (blue line) shows that, the width of 3 mm give a results 2379.51 R/sq, meanwhile the width of 5 mm give the average resistance is 2039.58 R/sq. The width of 7 mm gives the lower result among the width in 15 minutes of curing time, 1926.27 R/sq. So that, the higher result for the resistance is 3 mm of width. The better average of resistance is lower, then, the width of 7 mm gives the lower average of resistance

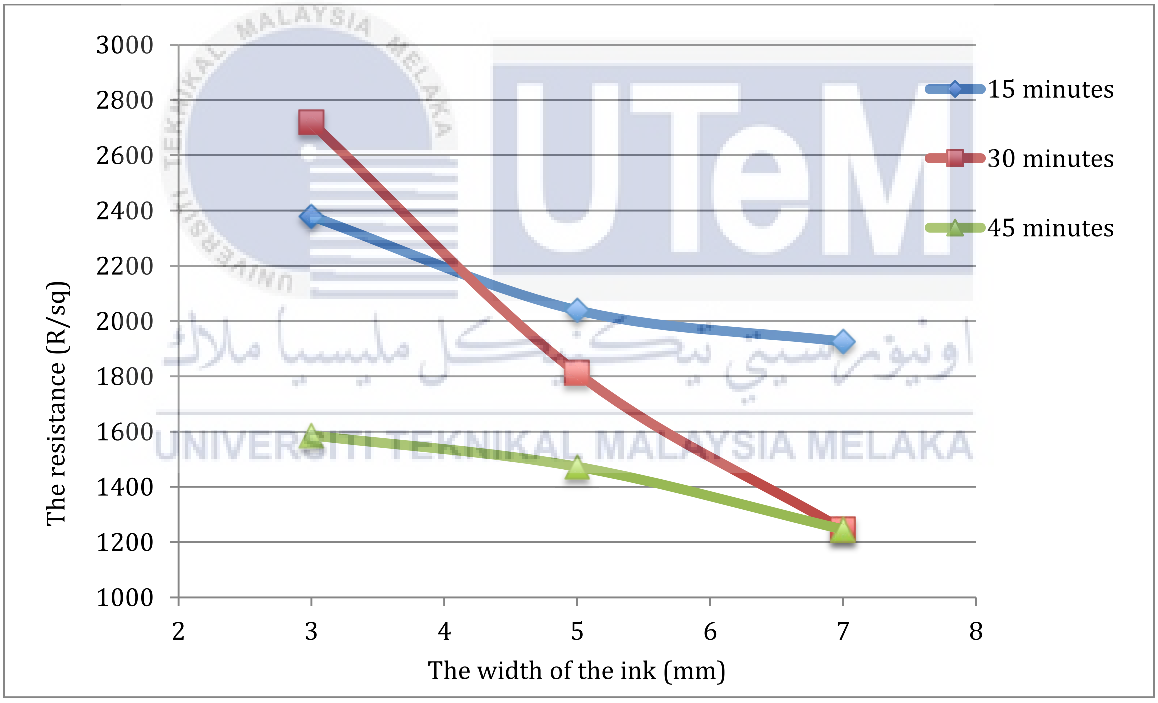

Figure 4.5: The Different Width result thickness 0.4 mm and length 60 mm

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The graph also shows the result for the 30 minutes and 45 minutes of curing time with different width. The results give the higher result at 3 mm width for 30 minutes of curing time, the average resistance is 2719.44 R/sq and for the 45 minutes is 1586.34 R/sq. The result give the lower resistance at 7 mm width for both curing time 30 minutes and 45 minutes, 1246.41 R/sq and 1246.41 R/sq. From the pattern graph above, it can be conclude that the bigger the width of the ink, the lower the resistance it will give.

Furthermore, the curing time also affect the average of the resistance. From the graph, it shows that the 45 minutes (green line) curing time at the bottom. So that it can be conclude, the longer the curing time, the lower the average resistance will get.

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c) Thickness 0.6 mm and length 80 mm

The graph below shows in the figure 4.6 the result for the effect of width on the conductive ink. The graph also shows the difference result for 3 different curing times, which is 15 minutes (blue line), 30 minutes (red line) and 45 minutes (green line). The result for 15 minutes (blue line) shows that, the width of 3 mm give a results 1359.72 R/sq, meanwhile the width of 5 mm give the average resistance is 1019.79 R/sq. The width of 7 mm gives the lower result among the width in 15 minutes of curing time, 906.48 R/sq. So that, the higher result for the resistance is 3 mm of width. The better average of resistance is lower, then, the width of 7 mm gives the lower average of resistance.

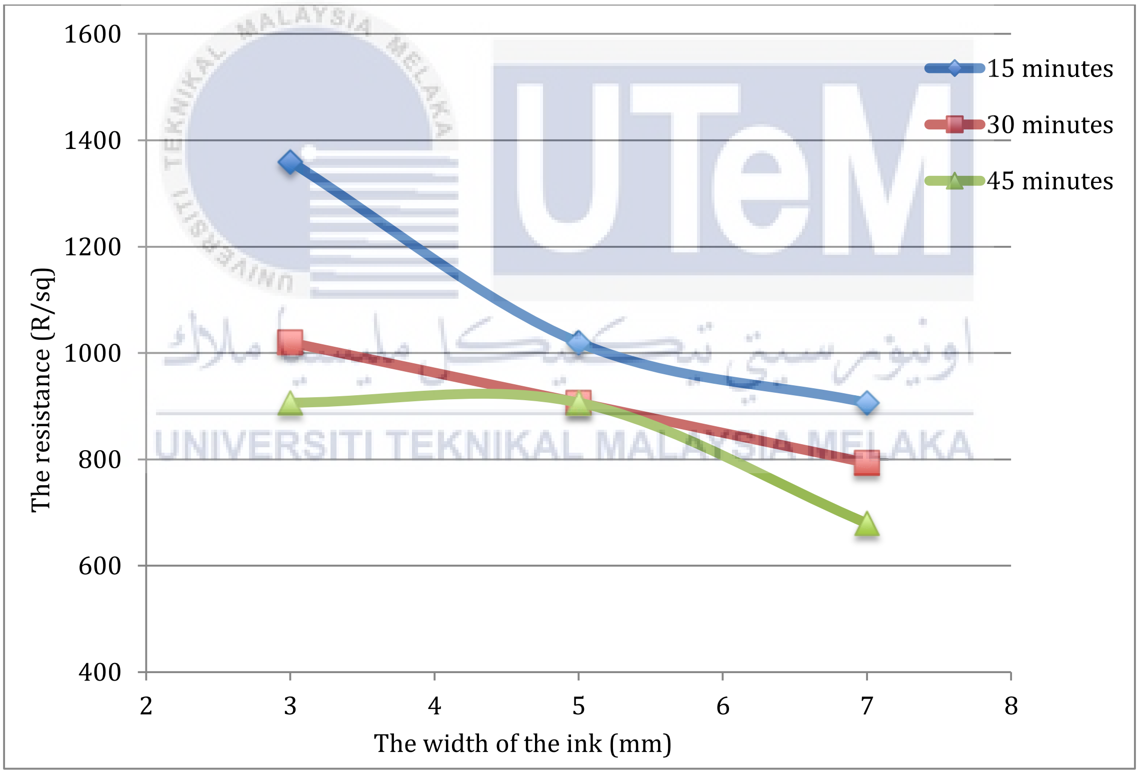

Figure 4.6: The Different Width result thickness 0.6 mm and length 80 mm

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The graph also shows the result for the 30 minutes and 45 minutes of curing time with different width. The results give the higher result at 3 mm width for 30 minutes of curing time, the average resistance is 1019.79 R/sq and for the 45 minutes is 906.48 R/sq. The result give the lower resistance at 7 mm width for both curing time 30 minutes and 45 minutes, 793.17 R/sq and 679.86 R/sq. From the pattern graph above, it can be conclude that the bigger the width of the ink, the lower the resistance it will give.

Furthermore, the curing time also affect the average of the resistance. From the graph, it shows that the 45 minutes (green line) curing time at the bottom. So that it can be conclude, the longer the curing time, the lower the average resistance will get. According to the resistance law, the smaller space has a higher resistance than a bigger space because it makes a less electron to pass through. This is the same as the effect of the width, the bigger the width, the lower the resistance will flow. The bigger width will make a electron through easily to flow and give a lower resistance to it. Furthermore, the black carbon provide better conductivity and good in electrical properties (Han & Fina, 2011). The ink has a lower resistance because after the ink was curing in the oven the particle in the ink will expand and reduce the gap between the filler. This make the electron will flow easily to flow and had a low resistance (Banfield, 2000). The result also had been approved by (Sobri & Rozali, 2018) that the experiment had been done and the result are the same.

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4.3 The effect of thickness on the conductive ink

(a) Length 40 mm and width 3 mm

The graph below in figure 4.7 shows that the result on affect of thickness on the conductive ink. There are 3 condition, which is same length and width but different thickness. The thickness has 3 parameter, 0.2 mm, 0.4 mm and 0.6 mm. The 3-colour line represents the different curing time. The 15-minute (blue line), 30 minutes (red line) and 45 minutes (green line)

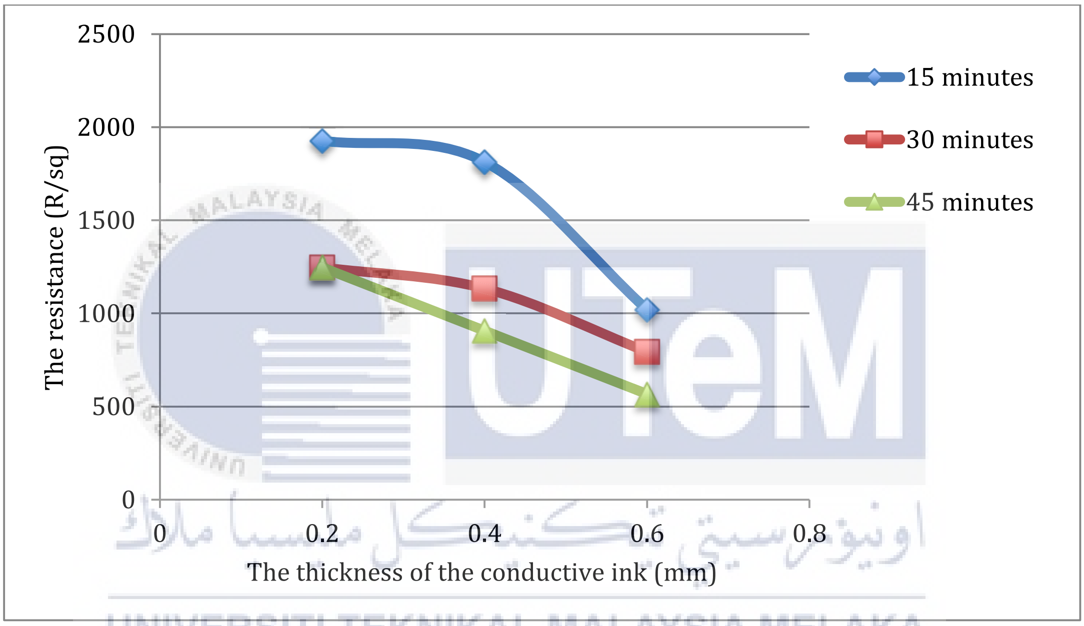

Figure 4.7 : The Different Thickness result Length 40 mm and width 3 mm

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The result shows that at the thickness 0.2 mm the result of the resistance is same between 30 minutes and 45 minutes, 1246.41 R/sq. The resistance for 15 minutes at 0.2 mm is 1926.27 R/sq is higher than the 30 and 45 minutes resistance. The result shows that the lower resistance at the 0.6 mm of thickness. The 15 minutes curing time give the resistance 1019.79 R/sq, meanwhile the 30 minutes and 45 minutes give the result of resistance is 793.17 R/sq and 566.55 R/sq. So that, it can be conclude that the higher the thickness of the ink, the lower the resistance of the conductive ink. Beside that, from the graph above the curing time also can be conclude that the longer the curing time, the lower the resistance of the conductive ink.

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b) Length 60 mm and width 5 mm

The graph below in figure 4.8 shows that the result on affect of thickness on the conductive ink. There are 3 condition, which is same length and width but different thickness. The thickness has 3 parameter, 0.2 mm, 0.4 mm and 0.6 mm. The 3-colour line represents the different curing time. The 15-minute (blue line), 30 minutes (red line) and 45 minutes (green line).

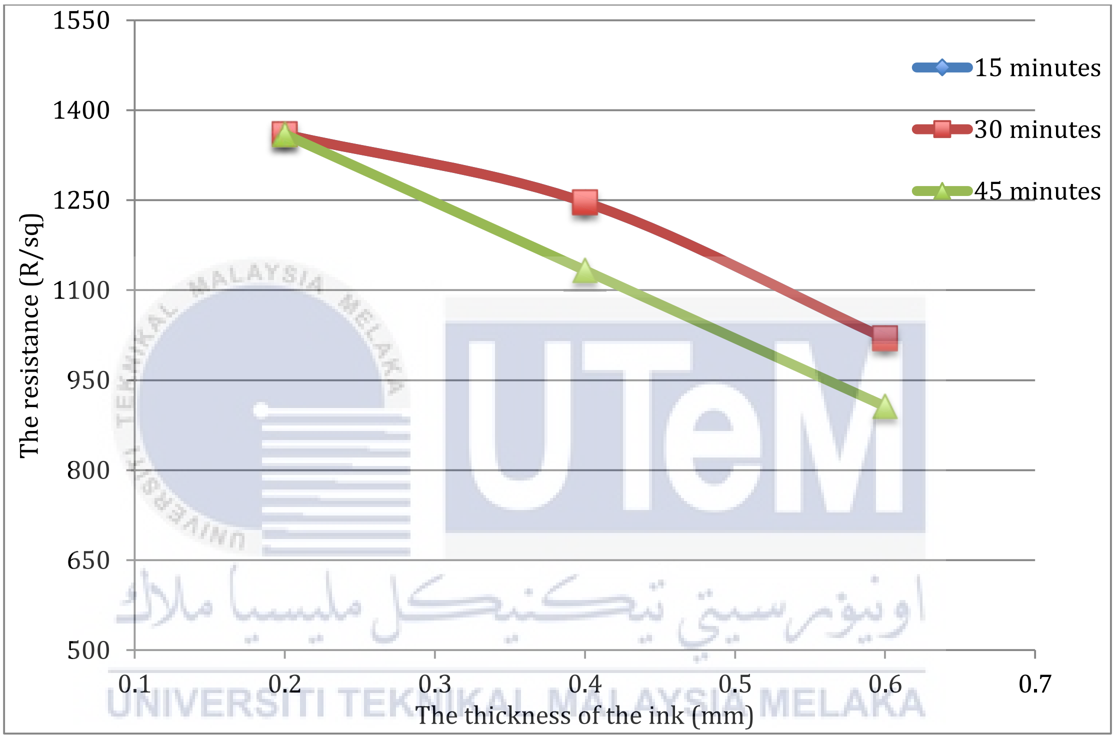

Figure 4.8 : The Different Thickness result length 60 mm and width 5 mm

The graph shows that the result for 15 minutes and 30 minutes are the same for this condition. The results give the higher resistance at the 0.2 mm of thickness 1359.72 R/sq and the lower resistance at the 0.6 mm is 1019.79 R/sq. For the 45 minutes the result give a lower resistance than the 30 and 15 minutes of curing time, but at the 0.2 mm the results still the same until at the 0.6 mm the resistance become lower 906.48 R/sq. it can conclude that the thicker the thickness of the ink, the lower the resistance of the conductive ink. Beside that, from the graph above the curing time also can be conclude that the longer the curing time, the lower the resistance of the conductive ink.

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c) Length 80 mm and width 7 mm

The graph shows in figure 4.9 below shows that the result on affect of thickness on the conductive ink. There are 3 condition, which is same length and width but different thickness. The thickness has 3 parameter, 0.2 mm, 0.4 mm and 0.6 mm. The 3-colour line represents the different curing time. The 15-minute (blue line), 30 minutes (red line) and 45 minutes (green line).

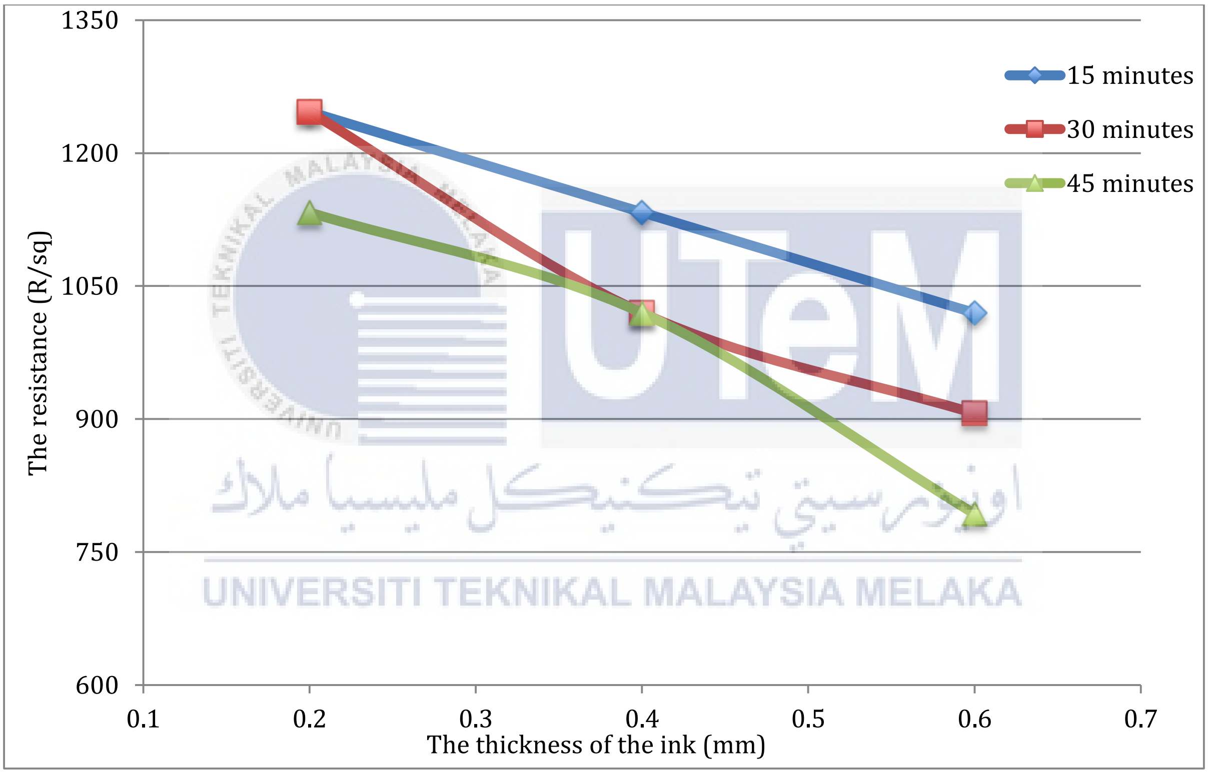

Figure 4.9 : The Different Thickness result Length 80 mm and width 7 mm

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The result shows that at the thickness 0.2 mm the result of the resistance is same between 15 minutes and 30 minutes, 1246.41 R/sq. The resistance for 45 minutes at 0.2 mm is 1133.1 R/sq is lower than the 30 and 45 minutes resistance. The result shows that the lower resistance at the 0.6 mm of thickness. The 15 minutes curing time give the resistance 1019.79 R/sq, meanwhile the 30 minutes and 45 minutes give the result of resistance is 906.48 R/sq and 793.17 R/sq. So that, it can be conclude that the higher the thickness of the ink, the lower the resistance of the conductive ink. Beside that, from the graph above the curing time also can be conclude that the longer the curing time, the lower the resistance of the conductive ink.

For the thickness, the thicker the ink, the more conductive filler in the ink, so that, the electron will through easily because of the quantity of the conductive filler are higher. The result also had been approved by (Suhaimi et. al., 2018) that the experiment had been done and the result has the graph pattern are the same. According (Suhaimi et. al., 2018), the conductive ink are depend on the quantity of the filler. So that, the higher the quantity of the filler the lower the resistnace of the conductive ink give.

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4.4 OBSERVATION OF SURFACE MICROSTRUCTURE AFTER CURING

In this section, the microstructure of the conductive ink will be discus deeply. There are some different value of the resistance between maximum value point and minimum point in a length. For example, in length 40 mm some point has a maximum and minimum value of the resistance on the conductive ink. There are several factors that affect the value of the resistance in a length.

a. 15 Minutes of Curing Time

i. Length: 40 mm

The maximum value of the resistance in this length is 1359.72 R/sq from point 1 and the minimum value in this length is 906.48 R/sq from point 2.

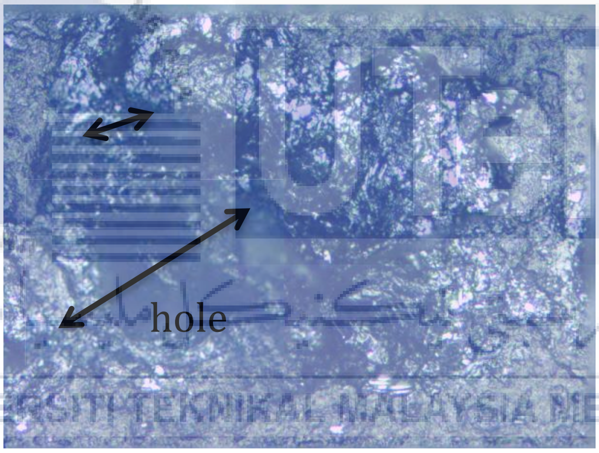

Figure 4.10: The microstructure from point 1

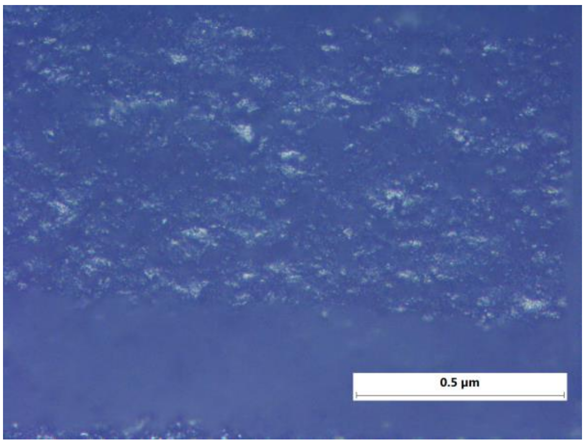

Figure 4.11: The microstructure from point 2

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Based on the figure 4.10 and figure 4.11 above show the different microstructure on the 40 mm that affect the value of the resistivity on the conductive ink. There are many type of defect on the microstructure that will affect the value of the resistivity.

Figure 4.10 show that the maximum value of the resistance give from point 1. From the figure, it shows that the microstructure has defect on the conductive ink cause the higher value of the resistivity. It obstructs the resistance to flow a long the 40 mm of the conductive ink. The hole on the ink has affect the result of the resistance on point 1 and give the highest value of the resistance.

Figure 4.11 show that the lower of the value resistance get from point 2. The surface and the microstructure on the point 2 have a smoother microstructure. So, the resistivity of the conductive ink not affect on the point 2 because that is no defect on the microstructure. The microstructure also closely to each other that causes the resistance easy to flow on the 40 mm of the conductive ink. So, it can be conclude that the defect on the microstructure will affect the value of the resistance. The bigger the defect on the conductive ink the higher the value of the resistivity will give.

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ii. Length: 80 mm

The maximum value of resistance on this length is 2266.20 R/sq and the lower value that gives on this length is 1359.72 R/sq.

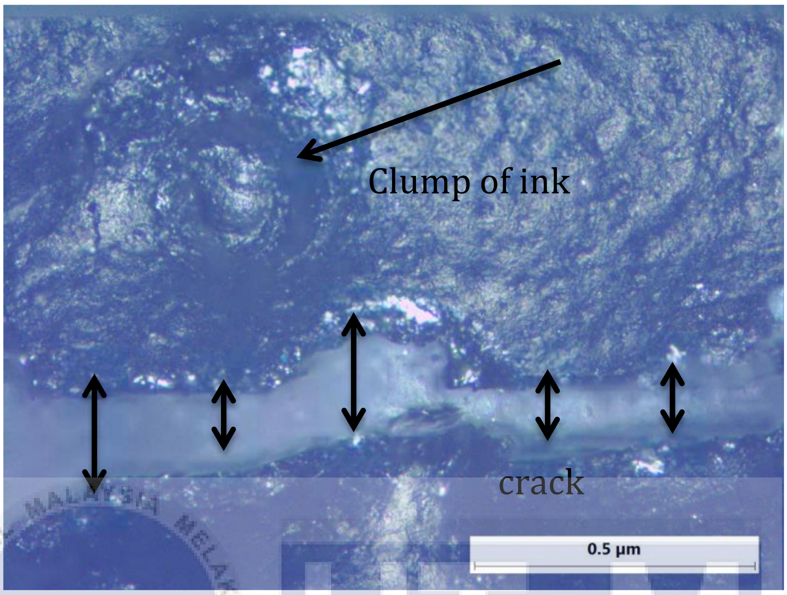

Figure 4.12: The microstructure from point 3

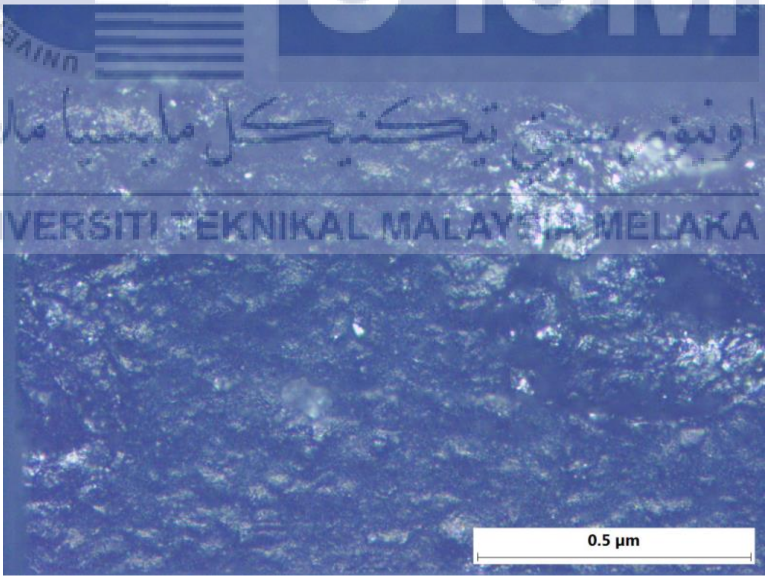

Figure 4.13: The microstructure from point 4

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From the figure 4.12 and figure 4.13 shows the different of microstructure between the maximum and minimum value of the resistivity. In the length of 80 mm, the different are quite notable and the different values are too large.

Figure 4.12 shows that the cracks in the conductive are too large. So, the resistances are difficult to flow and give the higher value of resistance. Moreover, the reasons the different value is quite large because in point 4 have 2 defects on the microstructure, crack and the clump of the ink. This is because it make the resistance are difficult to flow and give the highest value of resistivity among the point.

Figure 4.13 shows that the microstructure of the point 3, which is it give the lower value of resistance. The microstructure in this point are 3 are smooth the particles also are tightly together that make the resistance are easily to flow. So, it can give the lower value of the resistance on the conductive ink point 3.

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b. 30 Minutes of Curing Time

i. Length: 40 mm

The maximum value of resistance on this length is 1359.72 R/sq and the lower value that gives on this length is 906.48 R/sq.

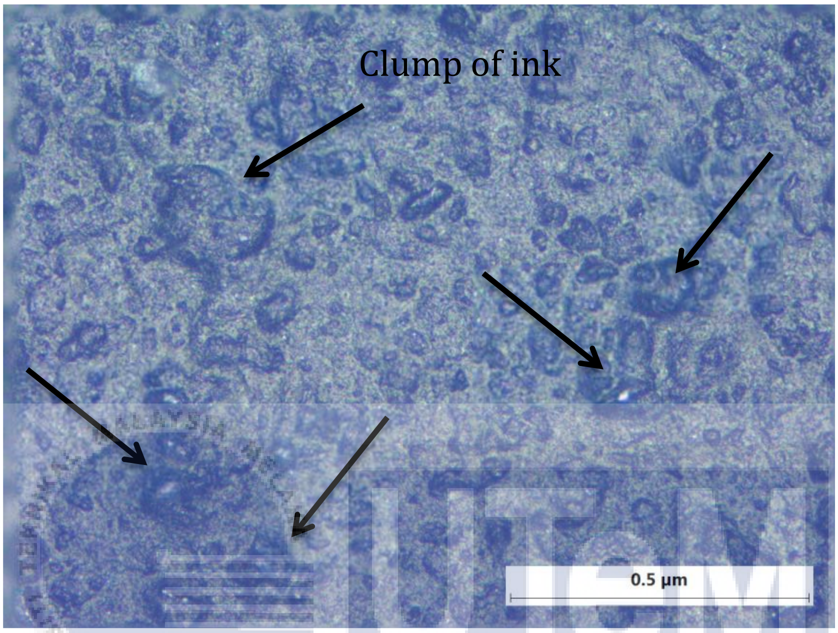

Figure 4.14: The microstructure from point 3

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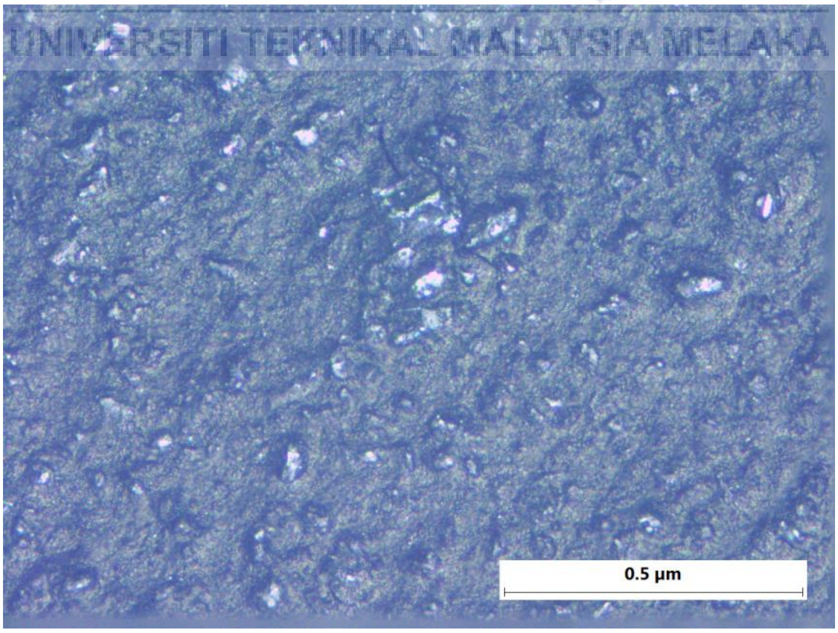

Figure 4.15: The microstructure from point 2

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The figure 4.14 shows that the microstructure from point 3, which is, gives the higher value of the resistance. The factor that these points give a higher value of resistance is there too much clump of the conductive ink, that is make a resistance difficult to flow and give the higher value of the conductive ink.

The figure 4.15 shows the microstructure of the lower value of the resistance. This point gives a lower value of resistivity because there are fewer defects on the microstructure. There are clump of ink but no too large and the resistance can flow easily through the particles. So, it gives a lower value of the resistance.

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ii. Length: 80 mm

The maximum value of resistance on this length is 1359.72 R/sq and the lower value that gives on this length is 906.48 R/sq.

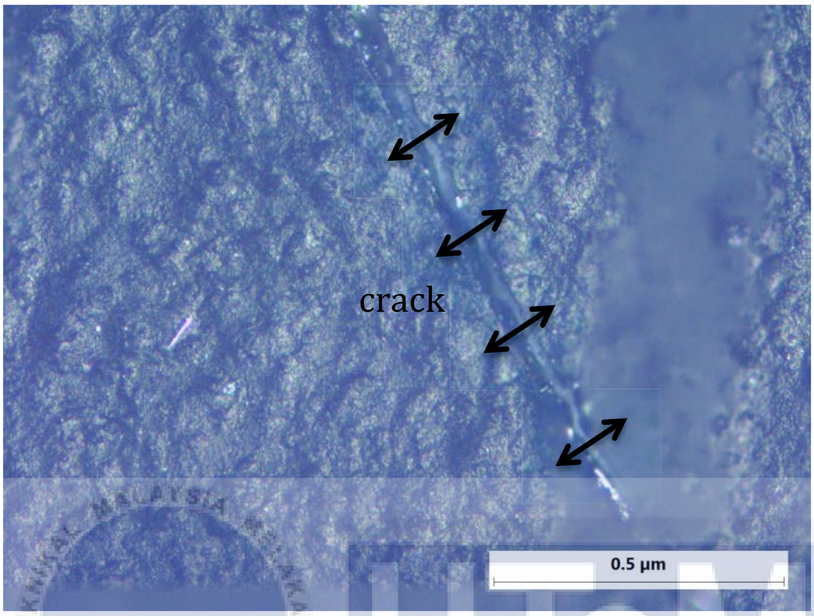

Figure 4.16: The microstructure from point 1

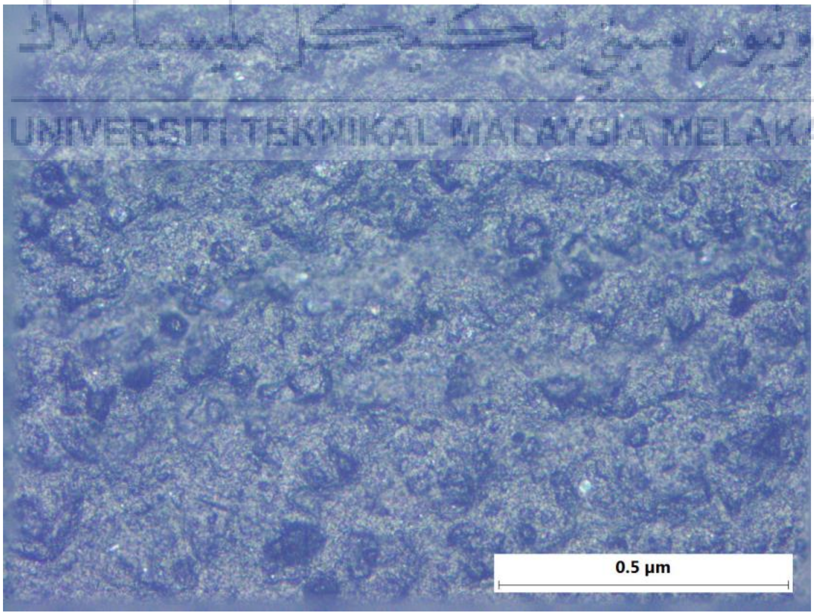

Figure 4.17: The microstructure from point 2

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The figure 4.16 are shows that the microstructure of the point 1 for the 60 mm length. This point give a higher value of the resistance because there is some crack at this point that makes a resistance difficult to flow and give a higher value of the resistance.

The figure 4.17 shows that the lower resistance values are give from this point because the particles are tightly together. So, it makes the resistance flow easily and give a lower value of the resistivity. From this observation, the fine a surface and the defect of particles will affect the resistivity of the stretchable conductive ink.

The defect of the conductive ink was influence by the printed the ink on the substrate. The ink must be printed on the TPU substrate carefully and uniformly to the area of the dimension. This is because if printed was not properly it might affect the microstructure before and after the curing the stretchable conductive ink and will give the higher resistance to the conductive ink. Moreover it might interfere with electron travel because of the defect of the ink and the specimen was not in a good condition.

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CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.0 CONCLUSION

In this chapter discussed about the conclusion and recommendation for the study based on the results had been obtained and analyze in previous chapter. The purpose for this analysis is to evaluate the effect of stretchable conductive ink in length, thickness and the width on electrical conductivity. Method to evaluate effect of stretchable conductive ink in length, thickness and the width on electrical conductivity.

(i) The Effect of Dimension on Resistance

The results has been obtained can be concluded that based on the effect of the dimension which the longer the dimension of the conductive ink, the higher the resistance. The higher resistance for the 15 minutes curing time is 80 mm which is it give a 1699.95 R/sq. the lower resistance for 15 minutes curing time is from 40 mm the value of resistance is 1133.1 R/sq.

From the result, the longer the length of the conductive ink, the higher the resistance value. For the 30 minutes of curing time, the lower resistance from 40 mm which is, 1019.79 R/sq and the higher value of resistance 1359.72 R/sq from 80 mm. Moreover, the curing time also effect the value of resistance, the lower resistance from 15 minutes curing time is 1133.1 R/sq and 1019.79 R/sq for the 30 minutes of curing time. From this situation, it can be conclude that, the longer the curing time, the lower the resistance value will get.

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The results shows that the dimension of width is influence the value of the resistance. From the result in this experiment, it can be conclude that the thicker the thickness of the conductive ink, the lower the value of the resistances. If the conductive ink has more thinner, it will shows the higher value of resistance on the four-point probe.

The results shows that the dimension of thickness is influence the value of the resistance. From the result in this experiment, it can be conclude that the width of the conductive ink, the lower the value of the resistances. If the conductive ink has a smaller size, it will shows the higher value of resistance on the four-point probe.

(ii) The Observation of Surface Microstructure

Then, the results for the microstructure of the conductive ink, which can be concluded that the microstructure also effect the resistivity of the conductive ink. If the microstructures have a defect, it will affect the resistance of the conductive ink. The many the defects on the microstructure, the higher the resistance of the stretchable conductive ink. The way to print the ink on the TPU substrate must uniformly to the area dimension of the ink; otherwise the microstructure will be defect.

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5.1 RECOMMENDATION

There are several suggestions to put into considerations for the future analysis, which is the changed, the curing temperature of the conductive to determined the size particle before and after the curing time. Moreover, its also can be determined the affect of the temperature on the conductive ink. Furthermore, it can analyze the particles in the ink after the stretchable conductive ink was cure by using scanning microscope electron. Last but not least, it also can investigate the hardener of the ink of the substrate, to find out there will affect the conductivity of the conductive ink.

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APPENDICES

(a) Different Length

(i) The Different length result thickness 0.2 mm and width 3 mm

Condition	40 mm	60 mm	80 mm
15 minutes	1133.1 (R/sq)	1359.72 (R/sq)	1699.65 (R/sq)
30 minutes	1019.79 (R/sq)	1133.1 (R/sq)	1359.72 (R/sq)
45 minutes	1019.79 (R/sq)	1133.1 (R/sq)	1699.65(R/sq)

;

(ii) The Different length result thickness 0.4 mm and width 5 mm

Condition	40 mm	60 mm	80 mm
15 minutes	1926.27 (R/sq)	2152.89 (R/sq)	2606.13 (R/sq)
30 minutes	1812.96 (R/sq)	2152.89 (R/sq)	2266.2 (R/sq)
45 minutes	1699.65 (R/sq)	2152.89 (R/sq)	2266.2(R/sq)

(iii) The Different length result thickness 0.6 mm and width 7 mm

condition	40 mm	60 mm	80 mm
15 minutes	2152.89 (R/sq)	2379.51 (R/sq)	2492.82 (R/sq)
30 minutes	1812.96 (R/sq)	2266.2 (R/sq)	2379.51 (R/sq)
45 minutes	1019.79 (R/sq)	1246.41 (R/sq)	1359.72 (R/sq)

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(b) Different Width

(i) The Different Width result thickness 0.2 mm and length 40 mm

Condition	3 mm	5 mm	7 mm
15 minutes	2039.58 (R/sq)	1812.96 (R/sq)	1699.65 (R/sq)
30 minutes	2379.51 (R/sq)	1926.27 (R/sq)	1812.96 (R/sq)
45 minutes	1699.84 (R/sq)	1019.79 (R/sq)	679.86 (R/sq)

(ii) The Different Width result thickness 0.4 mm and length 60 mm

Condition	3 mm	5 mm	7 mm
15 minutes	2379.51 (R/sq)	2039.58 (R/sq)	1926.27 (R/sq)
30 minutes	2719.44 (R/sq)	1812.96 (R/sq)	1246.41 (R/sq)
45 minutes	1586.34 (R/sq)	1473.03 (R/sq)	1246.41 (R/sq)

(iii) The Different Width result thickness 0.6 mm and length 80 mm

Condition	3 mm	5 mm	7 mm
15 minutes	1359.72 (R/sq)	1019.79 (R/sq)	906.48 (R/sq)
30 minutes	1019.79 (R/sq)	906.48 (R/sq)	793.17 (R/sq)
45 minutes	906.48 (R/sq)	906.48 (R/sq)	679.86 (R/sq)

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(c) Different thickness

(i) The Different Thickness result Length 40 mm and width 3 mm

Condition	0.2 mm	0.4 mm	0.6 mm
15 minutes	1926.27 (R/sq)	1812.96 (R/sq)	1019.79 (R/sq)
30 minutes	1246.41 (R/sq)	1133.1 (R/sq)	793.17 (R/sq)
45 minutes	1246.41 (R/sq)	906.48 (R/sq)	566.55 (R/sq)

(ii) The Different Thickness result Length 60 mm and width 5 mm

Condition	0.2 mm	0.4 mm	0.6 mm
15 minutes	1359.72 (R/sq)	1246.41 (R/sq)	1019.79 (R/sq)
30 minutes	1359.72 (R/sq)	1246.41 (R/sq)	1019.79 (R/sq)
45 minutes	1359.72 (R/sq)	1133.1 (R/sq)	906.48 (R/sq)

(iii) The Different Thickness result Length 80 mm and width 7 mm

Condition	0.2 mm	0.4 mm	0.6 mm
15 minutes	1246.41 (R/sq)	1133.1 (R/sq)	1019.79 (R/sq)
30 minutes	1246.41 (R/sq)	1019.79 (R/sq)	906.48 (R/sq)
45 minutes	1133.1 (R/sq)	1019.79 (R/sq)	793.17 (R/sq)

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