A STUDY ON ELECTRICAL PROPERTIES OF FLEXIBLE PRINTED ELECTRONIC CIRCUIT SUBJECTED TO CYCLIC BENDING LOAD

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

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DECLARATION

I admitted that this project entitled "A Study on Electrical Properties of Flexible Printed Electronic Circuit Subjected to Cyclic Bending Load" is the work of my own except as cited in the references.

Signature :…………………………………………..

Name :…………………………………………..

Date :…………………………………………..

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 the degree of Bachelor of Mechanical Engineering.

Signature :………………………………………………..

Supervisor Name :………………………………………..

Date :…………………………………………………….

ABSTRACT

This study investigates the reliability of printed conductive ink on flexible substrate under cyclic bending. The topic is focused on the resistance effect in conductive ink after being test with cyclic bending on different number of cycles. In this study, the test sample and specimens with various circuit width and thickness were printed on PET substrates. The test samples were printed using screen printing method. The conductive ink used was commercially obtained from Bare Conductive Ink. The ink was water and SWCNT based. The sample prepared were varied in term of circuit line width (1.0mm, 1.5mm, 2.0mm, 2.5mm and 3.0mm) and circuit line thickness (0.05mm, 0.10mm, 0.15mm, 0.20mm and 0.25mm). The readily sample was measured in term of its resistivity prior to bending tests. All of the sample prepared was later subjected to repeated bending cycles of 500, 1000, 1500, 2000 and 2500 times at fixed bending speed of 0.6 second per cycle on 11 volts. The circuit resistance was taken after the bending test. Finally, all of the samples was analyzed by using image analyzer. Results comparison between initial resistance and final data was conducted. The initial resistance without undergo bending cycle shows that the increasing of circuit line width resulting on decreasing of resistivity, while for thickness sample shows the same result where increasing of circuit thickness, resistivity of the circuit decrease except 0.20mm of thickness samples. Additions of ink volume used, means more electron can pass on the circuit and resulting on better conductivity. Meanwhile, for the sample of complete bending cycles, the resistivity tends to decrease when number of cycles increase for the width and thickness samples except for 2.5mm of width and 0.25mm of thickness sample. Up to 2500 cycles, the circuit resistivity is less affected by cyclic bending load.

ABSTRAK

Kajian ini menyiasat kebolehpercayaan dakwat konduktif di cetak pada substrat fleksibel dan dikenakan kitaran lenturan dan memberi tumpuan kepada kesan rintangan dalam dakwat konduktif selepas ujian. Dalam kajian ini, sampel ujian dan spesimen dengan lebar dan ketebalan litar yang berlainan telah dicetak pada substrat PET. Sampel ujian dicetak menggunakan kaedah percetakan skrin. Dakwat konduktif yang digunakan diperoleh secara komersil daripada Bare Conductive Ink. Dakwat itu berasaskan air dan SWCNT. Sampel disediakan bervariasi dari segi lebar litar (1.0mm, 1.5mm, 2.0mm, 2.5mm dan 3.0mm) dan ketebalan litar (0.05mm, 0.10mm, 0.15mm, 0.20mm dan 0.25mm). Sampel yang telah siap diukur rintangannya sebelum ujian lenturan. Kesemua sampel yang disediakan kemudiannya melalui kitaran lenturan berulang 500, 1000, 1500, 2000 dan 2500 kali pada kelajuan lenturan tetap 0.6 saat setiap kitaran pada 11 volt. Rintangan litar telah diambil selepas ujian lenturan. Akhir sekali, semua sampel dianalisis dengan menggunakan penganalisis imej. Perbandingan keputusan antara rintangan awal dan data akhir dijalankan. Rintangan awal tanpa menjalani kitaran lenturan menunjukkan bahawa peningkatan lebar litar menghasilkan penurunan rintangan, sedangkan untuk sampel ketebalan menunjukkan hasil yang sama di mana peningkatan ketebalan litar, rintangan akan menurun kecuali pada 0.20mm sampel tebal. Penambahan jumlah dakwat yang digunakan, bermakna lebih banyak elektron boleh melalui pada litar dan menghasilkan kekonduksian yang lebih baik. Sementara itu, untuk sampel kitaran lenturan yang lengkap, rintangan cenderung untuk menurun apabila bilangan kitaran meningkat untuk sampel lebar dan ketebalan kecuali 2.5mm lebar dan 0.25mm sampel tebal. Sehingga 2500 kitaran, resistensi litar kurang dipengaruhi oleh beban lenturan kitaran.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

The study to complete this project was basically to know the reliability of the commercial bare conductive ink printed on polyethylene terephthalate (PET) substrate or to determine the circuit resistivity toward cyclic bending. It is also being to know the difference in resistivity of the circuit when cyclic bending was given to the sample and without cyclic bending test toward the sample. The study is to know the resistivity of the circuit when some cyclic bending force with set of curvature radius has been applied toward the circuits substrate. The circuit needed are some circuit that can be printed by ink or the specially ink used. The ink used is bare conductive ink where it is ink filled with carbon that can conduct electricity. The ink is basically normal ink that has been mixed with some conductive material and can be used on substrate surface or any applicable surface.

Nowadays, printed electronics are currently developing as it can be used at many item. The. manufacturing industry currently use this kind of method to produce their product. Furthermore, printed electronics will be grow into bigger business in the future as its technologies has a lot of advantage and can be manufactured at low cost (Chrisey, 2000). The material used in this project are bare conductive ink where the ink is carbon based. The ink cure in room temperature and does not need oven to harden it. The substrate used were polyethylene terephthalate or PET. PET are plastic sheet where it can be printed on both side. This printed circuit or printed electronics are created by using a lot of variety techniques in the making of printing process. And for this project, the printing technique use was screen printing where the sample target was to have the even surface. For the resistivity data, it was to plot the graph of resistivity against number of cyclic bending cycle and find the standard deviation of the data collected.

1.2 Problem Statement

Flexible printed electronic (FPE) was growing and adapting very fast into daily application. Among potential type of filler in producing conductive paste for FPE is single-wall carbon nanotube (SWCNT). Carbon nanotubes offers many advantages especially in term of high electrical conductivity and good mechanical properties which was comparable to conventional silver-based nanoparticles. However, based on current literature review, there are still limited reports on studies involving the relationship between conductive layer geometrical parameters to the electrical performance of FPE made from SWCNT paste. In addition, reports on the effect of cyclic bending load for commercial SWCNT / PET substrate resistivity prepared at varying circuit line width and thickness was also scarce in current literature review.

1.3 Objective

The main objectives in completion of this project are

i. To prepare flexible printed circuit using conductive ink at varying circuity width and thickness.
ii. To determine resistivity and performance of printed electrics circuit after being subjected to cyclic bending loads.

1.4 Scope

The scopes of the project are: -

i. To performed literature review
ii. To identified the material needed to prepare the sample
iii. To designed the circuit
iv. To prepare and set up the facility for sample preparation and testing
v. To prepare the sample to undergo the bending test
vi. To test the sample and perform data collection using cyclic bending test apparatus
vii. To analyze the collected data
viii. To prepare the final report based on FKM UTeM thesis writing guidelines

In addition, the project deals with commercial type of conductive ink which is commercial type conductive ink obtained from Bare Conductive Ltd, United Kingdom. The ink then is printed on the surface of polyethylene terephthalate (PET). PET substrate was obtained from Lohmann Technologies UK Ltd, United Kingdom. The ink printing process used is screen printing.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

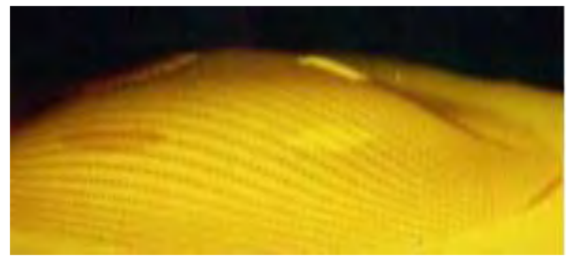
In this chapter, literature reviews conducted encompassed information on polyethylene terephthalate substrate, conductive ink, testing method for flexible printed circuit, and preparation method on the electrical circuit used. The main point included are substrate, ink, bending test, and printing techniques with details description on each point.

2.2 Flexible Electronics

Flexible electronics used majorly in technology for electronic circuits. The production of flexible electronics is through assembly the electronic devices on the any kind of compatible substrate surface. Plus, to print the flex circuits, it can be printed by using conductive ink. Flexible electronics created to replace the hard printed circuit boards, PCB where flexible electronics allow to form in desired shape. Throughout the history of flexible circuit, to raise the power and weight ratio, any kind of item thinned become flexible so silicon solar cells were thinned to ~100µm. Next, the thinned solar cells were then assembling on plastic substrate to obtain flexibility in forty years ago. Through flexible means, it can link with lightweight, bendable, elastic and large area. Today's researchers mostly focus on flexible shaped displays and sensors, electronic textiles and skin (Wong & Salleo, 2009).

In terms of mechanical characteristics for flexibility, it can be classified in three different categories which shown in Figure 2.1: (a)roll able or bendable, (b)elastically shaped and (c)permanently shaped. Flexibility in different means can have many different type of properties in terms of manufactures and users.

(a)



(b)

(c)

Figure 2.1: (a)Bendable circuit (b)Silicon island on spherically shaped foil substrate (c)Concept of conformably shaped digital dashboard (Wong & Salleo, 2009)

The electrical connections that used flexible circuits stands as one amongst the most advanced and important technologies as because of their useful and beneficial properties as example is their marginal weight, flexible form factors and thinness. For the application in whole devices, it can help in boost the device functionality by provide portability, freedom of form or flexible, impact resistance, reducing the product weight and thickness (Mitsui et al., 2015).

2.3 Conductive Ink

Conductive ink is an ink that use in a printable surface which they will conducts power. It is commonly made by adding and mix graphite or other materials that can conducts electricity into ink. Conductive inks can be a cheaper approach to set out a modern conductive traces where it can be compared with ordinary industrial standards, for example, drawing copper from copper plated substrates to shape the same conductive follows on relevant substrates, as printing is a simply added substance process creating no waste streams which at that point must be recovered or treated.

There are many types of conductive inks that we can found and use. All of this inks have their own weakness and also advantages that can be applied when they have been printed on substrate or any printable surface. The conductive inks that can be found are formulated based on carbon/graphene, silver flake, silver nanoparticle, carbon nanotube ink, copper flake, copper nanoparticle and conductive polymer.

When the inks contain of highly conductive metal such as copper, gold and silver, it can have classified as conductive inks. For conductive inks, it can separate into two types which is particle and nano-particle where it also can separate into two groups which is organic and non-organic because the solvent used ink the ink was different (Khirotdin et al., 2016).

The electrical properties of different such inks that utilize different sorts of carbon are because of a complex arrangement and interact between the morphology and size of the individual parts, their innate properties and the handling techniques used to scatter them (Phillips et al., 2017).

2.3.1 Carbon Ink

The type of ink that used in this project are carbon based ink or graphene. Nonetheless, graphene, the allotrope of carbon nanotube, is an extremely encouraging material for remote wearable communication applications thanks to its conductivity which mainly high and it properties is one of a kind which unique. Nowadays, researchers and scientist have done some intense investigation towards the usage of graphene or carbon to produce active device like diodes and transistors. Based on that, computerized modulator was achieved by utilizing two graphene transistors (Huang et al., 2016)

Carbon inks have a large group of ideal attributes that enable them to be utilized as a part of these applications, counting synthetic idleness, the capacity to be altered or, then again functionalized on case of electrochemical sensors and capacity to go about as intercalating materials in the instance of vitality stockpiling, and additionally minimal effort and disposability. Carbon inks are applied in established technology where it was used to make sensors for blood glucose (Phillips et al., 2017)

2.4 Substrate

There plenty of substrate which can be used as each of the surface has their own surface resistivity. The substrate that has been commonly used for conductive ink are Polyethylene Terephthalate (PET), Polypropylene (PP), Polyvinyl Chloride (PVC) and some of various types of paper. For this project, polyethylene terephthalate or PET has been choosing to complete the project. The surface of PET is commonly having smooth surface as it will help in printing the circuit. Rough surface will greatly affect the circuit as it will result of uneven contact between the ink and surface. Furthermore, rough surface will be causing missing dots on the circuit (Aijazi, 2014).

Any kind of flexible substrate used in flexible electronics must at least meet the requirements of optical properties, surface roughness, thermal and thermochemical properties, chemical properties, mechanical properties, electrical and magnetic properties (Wong & Salleo, 2009). Table 2.1 summarized the requirements for flexible electronics substrate material.

Table 2.1: Summary of the requirements for flexible electronics substrate material

Material properties	Requirements
Optical properties	Trans missive and bottom emitting displays uses clear substrates
Surface roughness	The sensitivity of electrical function toward surface roughness relies on the how much thinner the device films. Usually, plastic substrate rough only for over long distance
Thermal and thermochemical properties	the temperature for working environment with the substrate must be appropriate and compatible with maximum fabrication process temperature
Chemical properties	The substrate used must not issue contaminants and should be inert against process chemicals
Mechanical properties	The substrate of high elastic modulus resulting in increasing of stiff and the devices layers will be supported by hard surface under impact
Electrical and magnetic properties	Conductive substrate may fill in as common node and as an electrochemical shield. Coupling capacitance minimize when the substrate is electrically insulating

2.5 Manufacturing Method for Flexible Electronics

In the making of flexible electronics, commonly to form the circuit on the surface of the substrate, it involves of printing process. Printed electronics is an innovation that has been constantly improving consistently. This innovation is utilized to produce electrical devices for example making of slim film transistors, capacitors, resistors, batteries and circuits. In printed electronics printing process, there are currently include different kind of method such as screen printing, lithography and rotogravure as shown in Figure 2.2, where it is known as low cost process in industry. Nowadays, an advanced technique has been introduced and it is inkjet printing. The printing can become cheaper, easy for mass production, more convenient, grants flexibility and sustainable (Jiang, 2012).

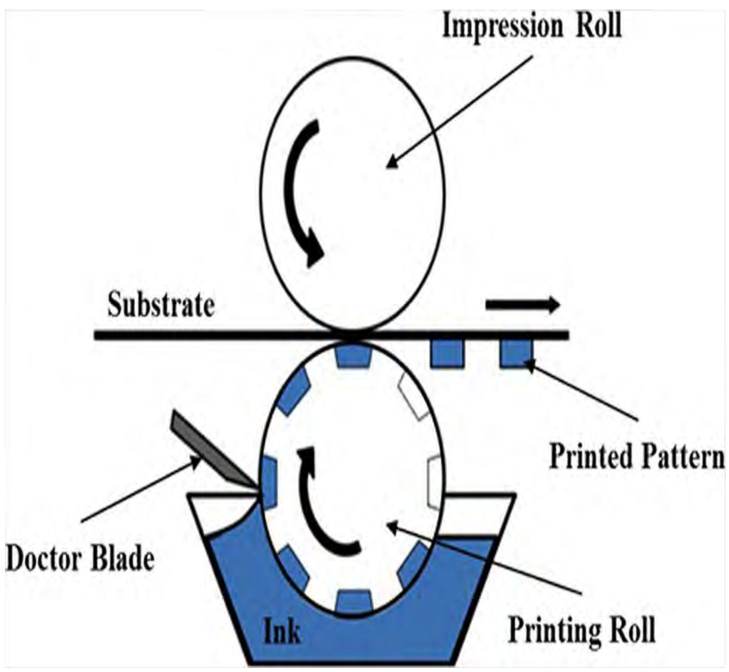


Figure 2.2: Rotogravure printing process (Hoffman et al., 2013)

Fabrication in flexible electronics by using of printing process promise a huge advantages especially in aspect of cost and simplicity compared to PCB manufacturing techniques (Ostfeld et al., 2015). Nowadays, industry more concern about energy consume during manufacturing and fabrication process of conventional electronics. The main attentions focus on finding additive ways to produce flexible electronics components an any substrates (Zheng et al., 2013). For the printing process, there are some plenty printing technologies that can be applied in printing conductive ink on substrate or any other surface. This printing process can be including in two different groups which is impact and non-impact printing technologies. The process type in making of sample of this project are based on screen printing which is under impact printing group.

For this impact printing, there are mainly four types and techniques under of impact printing group which screen printing is one of the techniques. Another three types are flexography, gravure and lithography. For the non-impact printing, the techniques can be form into six different ways. The printing techniques are electrophotography, iconography, magnetography, inkjet, thermography, and photography.

2.5.1 Screen Printing

Screen-printing utilizes a basic procedure in which a screen is conceal on the non-picture territories or area and has openings and graving in the picture regions. Ink is printed by applying the pressure to the screen and the picture is printed on the substrate. One of the greatest advantages of screen printing are the thickness of the printed ink film. The thickness can be varies based on screen thickness. This process is generally utilized as a part of the make of printed circuit boards. Screen printing also were accepted as one of the efficient way to produce and fabricate thermoelectric devices (Varghese et al., 2016).

The screen printing the has been introduces since 1980s offered large scale of manufacturing of highly reproducible but in reasonable price electrode systems. In the process of screen printing, it involving of the patterned deposition of inks onto surface of the substrate by squeezing the ink through screen mask and stencil. For the after printing treatment, it depends on varies of formulation where usually the ink cured at high temperature or let it dried at room temperature on certain period of time (Cai et al., 2010).

For the manufacturing industry, screen printing is one of the popular method to use. It will give form of design or ink which is thick on the substrate or any other surface. Screen printing can be divided into two methods which is flat bed screen printing and also rotary screen printing (Happonen, 2016). The procedure to complete the flat bed screen printing by putting the stencil on the substrate. Next by putting paste or ink on the stencil and pulling it along the stencil surface by using squeegee. Then remove the stencil and wet layer of ink remain on the substrate.

Screen printing methods has two different characteristics compare two other printing method which screen printing are versatile and its ink thickness can be variable. For the versatility of screen printing, it is can be used and apply on any kind of substrate. For the ink thickness, it can changes with different sets of speed, snap-off and pressure apply when pulling the ink by squeegee (Bhore, 2013).