EFFECT TYPE OF CONDUCTIVE INK TO STRETCHABLE PRINTED CIRCUIT UNDER THERMAL PERFORMANCE

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DECLARATION

I declare that the project entitled "Effect Type of Conductive Ink to Stretchable Printed Circuit under Thermal Performance" is the result of my own work except as cited in the references.

Signature : ....

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Date : ....

APPROVAL

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

Signature : ....

Supervisor's Name : ....

Date : ....

DEDICATION

I dedicated this thesis to my beloved family.

ABSTRACT

Polymer-based electrically conductive inks become as essential elements in flexible and stretchable electronics. The electrically stretchable conductive inks have been applied in various fields such as in biomedical, which is to detect the hydration of athlete's body. Stretchable conductive inks were also used in electronic devices and textile application due to the specialities that can withstand high stress conditions and tend towards high temperature. In order to develop stretchable conductive inks that have good electrical properties by considering the cost of production, further investigation must be done on the properties of the conductive ink. This study seeks to investigate the effects of thermal and mechanical test on sheet resistance of the conductive inks. This study also presents on how weight percentage of filler loading affected the resistivity. This study is focusing on the measurement of sheet resistance for two different types of conductive inks, which are carbon black and singlewalled carbon nanotubes by using four-point probe system and referred ASTM F390 as a guideline. Thermoplastic polyurethane was used as the substrate. For the thermal test, the samples were exposed to the four different level of temperature - 32 °C (room temperature), 40 °C, 60 °C and 100 °C. Hair dryer was used as tool to supply heat since it is easy to handle and can control the level of heat easily. Next, for the mechanical test, it is includes of strain test at 20 %, 40 %, 60 % and 80 % of elongation in room temperature condition. The strain test is conducted by using vernier callipers as a tool to provide strain. Scanning Electron Microscope (SEM) was used to analyzed the surface morphology and the determination wt.% of filler loading for both inks. As a result, it was found that sheet resistance of conductive ink were decreased as the temperature applied increase. However, for the strain test, sheet resistance increase with the increasing of strain applied. Eventually, the higher wt.% of filler loading contained in the conductive ink, the lower the sheet resistance value.

ABSTRAK

Dakwat konduktif yang berasaskan polimer menjadi elemen penting dalam elekronik yang bersifat kebolehlenturan dan boleh diregang. Dakwat konduktif boleh diregang telah digunakan dalam pelbagai bidang seperti dalam bidang bioperubatan, iaitu untuk mengesan penghidratan yang berlaku pada badan atlet. Seterusnya, ia juga digunakan dalam peranti elektronik dan aplikasi tekstil oleh kerana keistimewaannya yang dapat menahan keadaan yang bertekanan tinggi dan cenderung ke arah suhu yang tinggi. Untuk menghasilkan dakwat konduktif yang boleh diregang dan mempunyai sifat elektrik yang baik dengan mengambil kira kos pengeluaran, kajian yang lebih lanjut harus dilakukan ke atas sifat-sifat dakwat konduktif. Kajian ini adalah bertujuan untuk menkaji kesan ujian haba dan mekanikal ke atas rintangan elektrik dakwat konduktif. Selain itu, kajian ini juga membincangkan tentang bagaimana peratusan berat pemuatan pengisi mempengaruhi rintangan. Fokus kajian ini adalah terhadap pengukuran bacaan rintangan bagi dua jenis dakwat konduktif yang berbeza, iaitu karbon hitam dan karbon nanotiub berdinding tunggal dengan menggunakan sistem probe empat titik, dengan merujuk kepada ASTM F390 sebagai garis panduan. Termoplastik Poliuretana digunakan sebagai substrat. Bagi kajian haba, sampel didedahkan kepada empat suhu yang berbeza – 32 ° C (suhu bilik), 40 ° C, 60 ° C dan 100 ° C. Pengering rambut digunakan sebagai alat untuk membekalkan haba kerana ia mudah dikendalikan dan dapat mengawal tahap haba yang dibekalkan dengan mudah. Seterusnya, bagi ujian mekanikal, ia termasuk ujian ketegangan pada 20 %, 40 %, 60 % dan 80 % pemanjangan dalam keadaan suhu bilik. Ujian ketegangan dilakukan dengan menggunakan angkup vernier sebagai alat untuk memberikan regangan. Mikroskop pengimbas elektron (SEM) digunakan untuk menganalisis permukaan morfologi dan menentukan wt.% pemuatan pengisi untuk kedua-dua dakwat. Hasil menunjukkan rintangan dakwat konduktif telah menurun apabila suhu yang dikenakan ke atas sampel meningkat. Walau bagaimanapun, bagi ujian ketegangan, didapati bahawa rintangan meningkat dengan peningkatan tahap rengangan yang dikenakan ke atas dakwat konduktif. Akhir sekali, semakin tinggi nilai peratusan berat pemuatan pengisi di dalam dakwat konduktif, semakin rendah nilai rintangan dihasilkan.

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SPC	Stretchable Printed Circuit
PCB	Printed Circuit Board
SWCNTs	Singlewalled Carbon Nanotubes
MWCNTs	Multiwalled Carbon Nanotubes
CB	Carbon Black
TPUs	Thermoplastic Polyurethanes
PDMS	Polydimethylsiloxane
RT	Room Temperature
SEM	Scanning Electron Microscopy
CNTs	Carbon Nanotubes
TPEs	Thermoplastic Elastomers
SS	Soft Segments
HD	Hard Segments
T	Temperature
RT	Room Temperature

LIST OF SYMBOLS

wt.%	-	Weight percentage
Ag	-	Silver
Mg	-	Magnesium
Si	-	Silica
Rs	-	Sheet resistance
I	-	Current
V	-	Voltage

CHAPTER 1

INTRODUCTION

1.1 Background

The 1950s was a decade of the stretchable circuit was introduced in a very limited and slight way. It is also can be known as stretchable printed circuit (SPC). The simplest definition for stretchable printed circuit is a pattern of conductive traces bonded on stretchable substrates and in other words, it is a perfect solution for electronics packaging needs. Due to its capabilities and reliability, stretchable printed circuit has a valuable position compared to traditional printed circuit in worldwide printed circuits market. Stretchable printed circuit are being used widely in everyday technology and electronics in addition to high-end, complex completed components. The usage of SPC in modern portable electronics, hard disk and desktop printers are a few of the most outstanding examples.

Nowadays, stretchable printed circuit is mainly used in small or thin electronic institution compared to traditional printed circuit board. It is due to several good features of stretchable printed circuit compared to traditional printed circuit board (PCB). The first one is, SPC is highly stretchable and foldable compared to traditional PCB that is rigid. Next, stretchable printed circuit can be folding without affecting the signal transfer function. Application of the product also will be reduce, significantly reduce weight, increase function, cost reduction. Besides, printed circuit also anti-vibration due to the added flexibility and lighter weights allow the printed circuit to absorb and reduce the impact of the vibration to itself as well as any solder joints in connections. Stretchable printed circuit also can be use in harsh environment because it is built with materials that are have the waterproof, moisture proof, shock proof, high temperature oil and corrosion resistance properties.

In general, stretchable printed circuit comprising of filler, binder, solvent and substrate. There are a lot of different type of conductive filler that has being use in industry for example singlewalled carbon nanotubes (SWCNTs), multiwalled carbon nanotubes (MWCNTs), carbon black (CB), silver and graphene. Solvent also one of the important substances in the stretchable printed circuit that will increase the cross-linking of polymer. Cross-link is bond that links one polymer chain to another. Next, it is also a variety of material for improved thermal physical and chemical properties. Binder is a polymer, which for particle redistribution and restoration of conductivity upon solvent evaporation for example epoxy and resin. There are a few types of flexible substrate that has been used for example Thermoplastic Polyurethanes (TPUs) and Polydimethylsiloxane (PDMS).

Conductive inks are a mixture of conductive particles or filler, polymer binders, and dispersing solvents. The combination of the three elements will form conductive ink, which conducts electricity. They have been used in many electronics in industry for example in metallization of microcircuits, solar cells, large area electronic structures, and solder for microelectronics packages. Other than that, it is also technologies that compatible with many substrate surfaces including polyester, glass, and ceramics, and can be applied using screen.

This research will focus on the different types of conductive inks in stretchable printed circuit. Different conductive inks will have different properties. In other words, they will have the different in mechanical, thermal and physical properties that will affect the electrical conductivity of the conductive ink. The goal of this study is to investigate the effect thermal and strain on sheet resistance of different type's conductive ink.

In electronic industry, good conductivity of polymer-based conductive ink plays a big role that related to cost effective. Thermal conductivity that can be defines as a property of a material's ability to conduct heat while thermal resistance is a measure of a material's ability to prevent heat from flowing through it. In the other words, the greater conductivity, the lower its resistance.

1.2 Problem Statement

Over the past few years, in order to improve and upgrade the industry technologies, printed circuit board is invented from rigid printed circuit board to stretchable printed circuit board. This is due to the limitation of the usage rigid printed circuit in industry for example it has fixed mode or shape depending on the shape of the product, rigid and has no anti-vibration. The fixed board is replaced by flexible substrate since it has flexible and stretchable properties. Conductive inks that are both stretchable and flexible are performing as better application in stretchable printed circuit electronic devices. Therefore, the demand of highly flexible and bendable of printed circuit is grow rapidly. To have high quality of stretchable conductive ink, it must be able to expose with high level of temperature, capable on has good adhesive strength with the substrate while maintaining the electrical conductive performance. However, the current stretchable conductive ink have their own weakness which is it only can bend along single axis and cannot be comply with arbitrary shapes like for example surface texture of human skin. It is significant to do the further study on the effect of mechanical test to the electrical performance of the conductive ink while making it is suitable to be applied in high performance application. In this study, the mechanical test includes of strain for several elongation.

Next, the electrical performances, which are the conductivity of the stretchable conductive ink, also have certain limitation under the thermal application. As mention before, in order to improve the standard of the stretchable conductive ink, it must be able to be implemented at high temperature conditions. Therefore, it is very important to investigate the particle's behavior of the conductive ink and compatibility between inks with the substrate since the physical properties of the substrate might affect the performance of the stretchable conductive ink. The conductive ink that has been used in this study are singlewalled carbon nanotubes and carbon black, which has their own properties.

These problems will be study based on several parameters for example the effect of temperature and strain towards the resistivity of the conductive inks. Therefore, this research will cover on the effect of different type of conductive ink to stretchable printed circuit under thermal performance. CB and SWCNTs has been used to improve and enhance a better quality of stretchable printed circuit. Next, the aim of this study is to conduct experiment by using SWCNTs and CB that have a better conductivity and high strength in different condition applied.

1.3 Research Objective

The objectives for pursuing the current research topic are:

1. To determine the effect of temperature to sheet resistance of CB and SWCNTs for enhance the material properties.
2. To study the effects of strains to the sheet resistance of CB and SWCNTs at room temperature for upgrade the functionality.
3. To study the effects weight percentage of filler loading in the conductive inks to the sheet resistance for improve the electrical performances.

1.4 Scope of Project

The scopes of this project are listed as below:

1. Screen printing of conductive ink on TPUs substrate.
2. Measure sheet resistance of conductive ink using four-point probe:
   - Elevated temperature at 32 °C (RT), 40 °C, 60 °C and 100 °C
   - Strain at 20 %, 40 %, 60 % and 80 % of elongation
3. Surface morphology study by using SEM analysis.

1.5 Planning and Execution

The details of research activities for PSM I are shown as in Figure 1.1 below. Figure below illustrates the research activities for PSM 1 that includes the process of research title selection, literature review, designing the experiment, pre-experiment, formulation of samples, material characterization testing for thermal analysis, data validation, report writing and followed by report submission and lastly PSM I Seminar. The material characterization includes mechanical and thermal testing.

Activities \ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Research Title Selection	■	■												
Literature Review		■	■	■	■	■	■	■	■	■	■	■		
Design of Experiment	■	■	■											
Pre-experiment				■										
Formulation of Sample				■	■	■	■	■						
Characterization Testing i. Thermal							■	■	■	■	■			
Data Validation									■	■	■			
PSM I Report Writing				■	■	■	■	■	■	■	■	■		
PSM I Report Submission													■	
PSM I Seminar														■

Figure 1.1: Gantt Chart for PSM I Activities

For PSM II, the research activities started with the sample preparation for both conductive inks, which are CB and SWCNTs. Next, the activity is followed by the surface morphology study by using Scanning Electron Microscopy (SEM) analysis, characterization testing under thermal and mechanical test. SEM analysis was study to analyze the particles content in the both conductive inks. The thermal test includes of supplying elevated temperature to the samples starting with 40 °C, 60 °C and 100 °C. For the mechanical test, it is includes of applying strain at 20%, 40%, 60% and 80% of elongation to the samples. After all the testing completed, proceed with the data analysis, result and discussion. The research activities for PSM II stage are detailed out as in Figure 1.2 below.

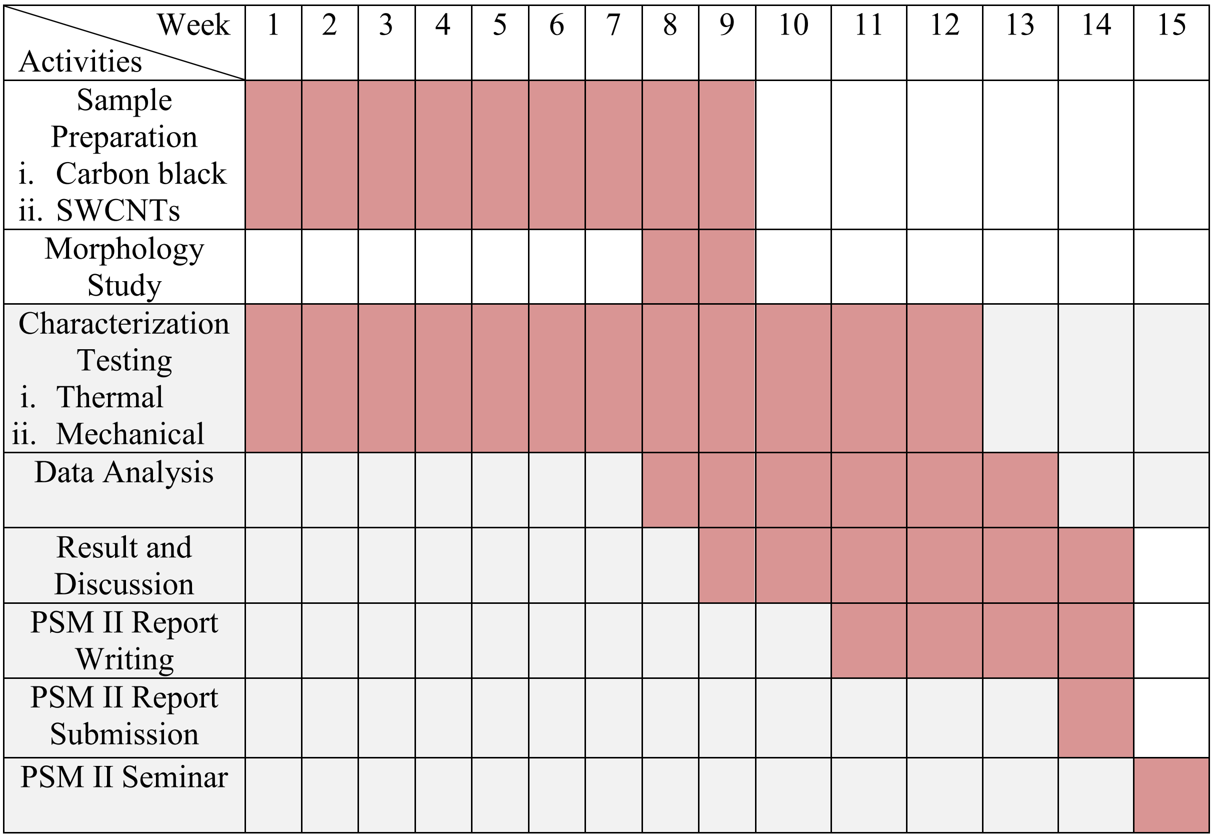

Figure 1.2: Gantt Chart of Activity Details and Their Respected Time Frame for PSM II

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, a review on conductive ink, filler, substrate, four-point probe system and the properties of the conductive ink including thermal, electrical and physical properties have been discussed further.

2.2 Conductive Ink

Conductive ink plays a big role in stretchable printed circuit. The definition of conductive in electrical view is the ability of the material or substances to conduct electricity. With high conductivity of the material, such as metal, the electric current will able to flow easily when voltage is exerted. It is also simply stated by D. Banfield (2000), material with lower resistance will conduct electricity more efficiently compared to material that has high resistance. Electrical resistivity or in other words, specific electrical resistance is a parameter to measure how potentially conductors to resist the flow of electric current. Next, the conductivity is inversely proportional to the resistivity, which is high conductivity of conductor or material will results a lower resistivity.

Nowadays, the market and manufacture conductive ink showing sign of growth due the high demand in industries. It is use in various type of industries such as industries of