PARAMETRIC STUDY ON THE DEVELOPMENT OF SUBSTITUTE MATERIALS FOR STRETCHABLE CONDUCTIVE INK (SCI) AS A FUNCTION OF CONDUCTIVE FILLER LOADING

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This report is submitted
in fulfilment of the requirement for the degree of
Bachelor of Mechanical Engineering (Structure & Materials)

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Faculty of Mechanical Engineering

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DECLARATION

I declare that this project report entitled "Parametric study on the development of substitute materials for Stretchable Conductive Ink (SCI) as a function of conductive filler loading" is the result of my own work except as cited in the references

Signature : ……………………………………

Name : ……………………………………

Date : ……………………………………..

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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 :. ……………………………

Name of Supervisor : ……………………………

Date : ……………………………

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DEDICATION

To my beloved mother and father

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ABSTRACT

In this study, a 15 µm Graphene Nanoplatelets (GNP) is used as a conductive filler in a Poly (3,4-ethylene dioxythiophene) Polystyrene Sulfonate (PEDOT: PSS) polymer matrix in formulating the stretchable conductive ink (SCI) in which the Thermoplastic polyurethane (TPU) is used as a substrate. The SCI system sets the GNP filler loading to 5, 7.5 and 10 wt.%. The parametric study includes establishing the optimum temperature, mixing time and mixing speed in the Thinky Mixer centrifugal mixer followed by curing in the oven. The ratio between materials used in the SCI formulation was calculated using the Rule of Mixture (ROM) for composites. The optimum process parameters established in this study are at a curing temperature of 60°C for 15 minutes. The optimum mixing time and speed in the Thinky Mixer is 10 minutes at a mixing speed of 400 rpm. Based on visual observation during the formulation of the SCI, to overcome the presence of brittleness of the cured SCI ink and the bubble formed in the blending of PEDOT: PSS with the GNP filler, surfactants were introduced. Dimethyl sulfoxide (DMSO), Mono Ethylene Glycol (MEG), and Triton-X100 were included in the optimum SCI formulation before the electrical characterization of the SCI. Based on the electrical characterization via a Four-point probe as per ASTM F390, an optimum average sheet resistivity is attained at a GNP filler loading of 10 wt.%, with a value of 3.97±0.46 Ω/sq., which yield in conductivity of 2518.9 S/m. Surface morphology of the SCI reveal traces of void formation at the lowest GNP filler loading of 5 wt.%, and better homogeneity is evident at increasing GNP filler loading. The preliminary results on the newly formulated SCI using these materials combination suggest a promising potential of the ink for uses in flexible electronics applications.

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ABSTRAK

Dalam kajian ini, 15 µm Graphene Nanoplatelets (GNP) digunakan sebagai pengisi konduktif dalam matriks polimer Poli (3,4-etilena dioksitiofen) Polistirena Sulfonat (PEDOT: PSS) dalam formulasi dakwat konduktif boleh renggang (SCI) di mana Poliuretana termoplastik (TPU) digunakan sebagai substrat. Sistem SCI ini menggunakan 5, 7.5 dan 10 wt.%. muatan bahan pengisi GNP. Kajian parameter di dalam projek penyelidikan ini mengambilkira suhu optimum, masa pencampuran dan kelajuan pencampuran dalam pengadun emparan *Thinky Mixer* diikuti dengan pengerasan di dalam ketuhar. Nisbah antara bahan yang digunakan dalam formulasi SCI dikira menggunakan Peraturan Campuran (ROM) untuk komposit. Parameter proses optimum yang ditetapkan dalam kajian ini adalah pada suhu pengerasan 60℃ selama 15 minit. Masa dan kelajuan adunan optimum dalam pengadun emparan *Thinky Mixer* ialah 10 minit pada kelajuan adunan 400 rpm. Berdasarkan pemerhatian visual semasa formulasi SCI, untuk mengatasi masalah kerapuhan dakwat SCI yang telah dikeraskan dan gelembung udara yang terbentuk di dalam adunan PEDOT: PSS dengan pengisi GNP, surfaktan telah diperkenalkan. Dimetil sulfoksida (DMSO), Mono Ethylene Glycol (MEG), dan Triton-X100 dimasukkan dalam formulasi optimum SCI sebelum pencirian sifat elektrik. Berdasarkan pencirian elektrik melalui kuar empat mata dengan merujuk kepada ASTM F390, kerintangan kepingan purata optimum dicapai pada muatan pengisi GNP sebanyak 10 wt.%, dengan nilai 3.97±0.46 Ω/sq., yang menghasilkan kekonduksian sebanyak 2518.9 S/m. Morfologi permukaan SCI mendedahkan kesan pembentukan lompang pada muatan pengisi GNP terendah iaitu 5 wt. %, dan kehomogenan yang lebih baik dapat dilihat pada peningkatan pemuatan pengisi GNP. Berdasarkan penemuan awal daripada kajian bahan SCI dengan formulasi baru yang menggunakan gabungan bahan-bahan yang dipilih ini menunjukkan bahawa dakwat ini mempunyai potensi untuk kegunaan di dalam aplikasi elektronik fleksibel.

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LIST OF ABBREVATIONS

3D	Three Dimensional
CNT	Carbon nanotubes
CVD	Chemical vapor decomposition
ECA	Electrically conductive adhesive
ICA	Isotropically Conductive Adhesive
MWCNT	Multiwall carbon nanotubes
NCA	Non-Conductive Adhesive
PDMS	Polydimethylsiloxane
SEM	Scanning Electron Microscope
SWCNT	Single wall carbon nanotubes
TPU	Thermoplastic polyurethane
UV	Ultra violet
GNP	Graphene Nanoplatelets
GCN	Graphene Carbon Nanoplatelets
DMSO	Dimethyl sulfoxide
MEG	Mono Ethylene Glycol
X-100	Triton X-100

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LIST OF SYMBOLS

μ = Micro

°C = Degree Celsius

k = Kelvin

Ω = Ohm

sq = Square

T_g = Glass temperature

g = Gram

m = Meter

nm = Nanometer

μm = Micrometer

L = Length

OD = Outer diameter

V_m = Volume of matrix

V_f = Volume of fiber

V_c = Volume of composite

wt% = Weight percentage

mm = Milimeter

τ = Shear

F = Force

A = Area

R = Resistance

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CHAPTER 1

INTRODUCTION

1.1 Background

Due to complex and expensive procedures, today's printed circuit board (PCB) producers pay relatively high costs. Stretchable conductive inks (SCI) have grown in popularity due to their high flexibility and expendability while keeping excellent conductivity. Due to the exceptional properties of nanocarbon-based materials (graphene and CNT), the fillers in SCI have to be moved from metallic to nanocarbon-based materials (graphene and CNT). However, there is a scarcity of good data on specific industrial-based applications, which has resulted in a lack of industry interest in exploring this technology. Furthermore, understanding the thermomechanical influence of nanocarbon-based materials in SCI, both on their functioning and dependability, is critical, and this knowledge is currently lacking. The usefulness, performance, and durability of replacing metal fillers with nanocarbon-based materials have yet to be thoroughly investigated. The process of creating SCI materials is arduous and time-consuming. (As a result, this research aims to find the best materials composition and ideal parameters for producing the SCI (A. S. Ashikin et al., 2019)

TPU is a high-performance thermoplastic elastomer used in coatings, adhesives, reaction injection moulding, fibers, foams, thermoplastic elastomers, and composites. TPU is a highly elastic material that can withstand up to 1000

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percent strains. According to Merilampi et al. (2009), many factors affect the sheet resistance of conductive ink, including curing ink conditions, ink viscosity, and filler content of ink. The consequences on the flexible and elastic substrate, on the other hand, have yet to be thoroughly understood. (A. S. Ashikin et al., 2013)

1.2 Problem Statement

Stretchable conductive inks (SCI) have grown in popularity due to their high flexibility and expendability while keeping excellent conductivity. To solve these issues, numerous conductive fillers are utilized in the printed electronics market, including gold, platinum, carbon nanotube, silver nanoparticles, and organic conductive polymers(Ashikin et al., 2013). Furthermore, graphene can be employed to reduce the manufacturing cost of PCB technology.

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The board is physically frail and can easily break when pushed under extreme pressure. Low manufacturing costs, long-term durability, environmentally sustainable production processes, recycling, lower energy consumption and improved efficiency, and electronic integration as part of other structures are all essential new electronic features. Copper, aluminium, and nickel are less expensive alternatives because of the high materials cost(Ashikin et al., 2013). However, one of these materials' drawbacks is that it is easily oxidized in the air, generating an insulating barrier on their surface. The SCI provides a one-of-a-kind solution for integrating electronics into apparel, accessories, and medical devices. The ink can be utilized to produce a thin, stretchy formfitting circuit in wearable devices that allows for both comfort and freedom. Because of its multiplexing mobility, one of the critical issues in wearable chemical sensors in real-life scenarios is that it can create poor deformations of wearable equipment, including power supplies and sensors.

The samples in this thesis were printed to reduce total production time and cost-effective with higher quantities because printing is a low-cost and quick means of manufacturing multiple samples. As demonstrated in a recent work, screen printing is one approach for creating conductive ink patterns directly on flat or even irregularly shaped and curved surfaces. Electronic circuits are printed using various technologies, including gravure printing, inkjet printing, and flexographic printing. (A. A. Ashikin et al.,2019)

1.3 Objective

The objectives of this project are as follows:

i. To develop a newly formulated SCI with varying GNP filler loading using optimum process parameters

ii. To characterize the electrical and mechanical properties of the newly formulated SCI.

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1.4 Scope of Project

The scopes of this project are:

- I. Formulating new nanocarbon-based SCI using different weight percent.
- II. Fabrication of the SCI with optimized formulation using a centrifugal mixer machine
- III. Electrical characterization of the SCI using a four-point probe iv. Mechanical characterization of the SCI using a customized jig for stretchability study
- IV. Morphological analysis of the SCI using a Scanning Electron Microscope (SEM)

1.5 General Methodology

In general, the following research activities will be sought throughout this semester for

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PSM I, as listed below: -

1. Literature review

   Journals, articles, or any published materials related to the project will be reviewed and analyzed.

2. Design of experiment (DOE)

   DOE is a powerful data collection and analysis tool used in various experimental situations. It allows multiple input factors to be manipulated, determining their effect on the desired output. In this study, a specific DOE software tool will be used to optimize the newly formulated SCI

3. Stretchable conductive ink (SCI)

   Conductive filler is a functional material that enables the ink film to have better electrical, which possesses good conductivity after stretching and folding. (Kim et al., 2020)

Table 1.1 demonstrates the research planning and activities for PSM I, while in Table 1.2, the research activities planned for PSM II. For this semester, upon confirmation of the chosen topic, a literature review is done to understand the research related to the project. Later, in Week 7, the progress report is due for submission.

From the established literature, the design of experimental work will be carried out using a specific tool. Next, formulation and fabrication of the SCI's samples will be carried out, and the analysis of the preliminary experiment will be made and analyzed. Finally, a report will be submitted, and the primary literature and preliminary results will be presented in the PSM 1 seminar.

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Table 1.1 The research planning and activities for PSM I

Activities/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Research title review	🟩														
Literature review					🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Design of experiment		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
Sample fabrication											🟩	🟩	🟩	🟩	
Testing/Data collection											🟩	🟩	🟩	🟩	
Data analysis											🟩	🟩	🟩	🟩	
Report writing		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
Report submission														🟩	🟩
PSM presentation															🟩

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Table 1.2 The research planning and activities for PSM II

Activities/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Literature review	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Design of experiment		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩			
Sample fabrication				🟩	🟩	🟩	🟩	🟩	🟩	🟩					
Testing/Data collection				🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
Data analysis					🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
Report writing						🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
Report submission														🟩	
PSM presentation															🟩

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter provides an overview of connection materials, electrically conductive adhesives, polymers, fillers, carbon nanotubes, and their mechanical, electrical, and thermal properties based on past research.

2.2 Stretchable Conductive Inks

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Stretchable conductive inks (SCI) have grown in popularity due to their high flexibility and expendability while keeping excellent conductivity. Due to the exceptional properties of nanocarbon-based materials (graphene and CNT), the fillers in SCI have to be moved from metallic to nanocarbon-based materials (graphene and CNT). However, there is a scarcity of good data on specific industrial-based applications, which has stifled industry enthusiasm in pursuing this technology for their products (Merilampi et al., 2009). Furthermore, understanding the thermomechanical impact of nanocarbon-based materials in SCI is critical for their functioning and reliability, which is currently lacking. The usefulness, performance, and durability of replacing metal fillers with nanocarbon-based materials have not been thoroughly investigated. The process of creating SCI materials is arduous and time-consuming. As a result, this research aims to find the best materials composition and ideal parameters for producing the SCI.