



**EFFECTIVENESS OF THE NEW FORMULATION OF  
GNP/SA HYBRID CONDUCTIVE INK ON TORSION/  
BENDING CYCLIC LOADING**



**MASTER OF SCIENCE IN MECHANICAL ENGINEERING**

**2024**



**Faculty of Mechanical Technology and Engineering**

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**Hazril Hisham Bin Hussin**

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

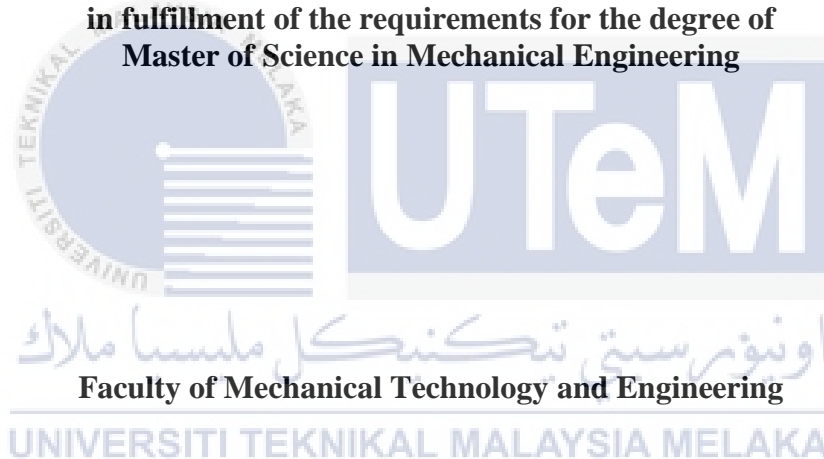
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CONDUCTIVE INK ON TORSION/BENDING CYCLIC LOADING**

**HAZRIL HISHAM BIN HUSSIN**

**A thesis submitted  
in fulfillment of the requirements for the degree of  
Master of Science in Mechanical Engineering**



**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2024**

## DECLARATION

I declare that this thesis entitled “Effectiveness of The New Formulation of GNP/SA Hybrid Conductive Ink on Torsion/Bending Cyclic Loading” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : .....

Name : Hazril Hisham Bin Hussin

Date : 24 September 2024



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## APPROVAL

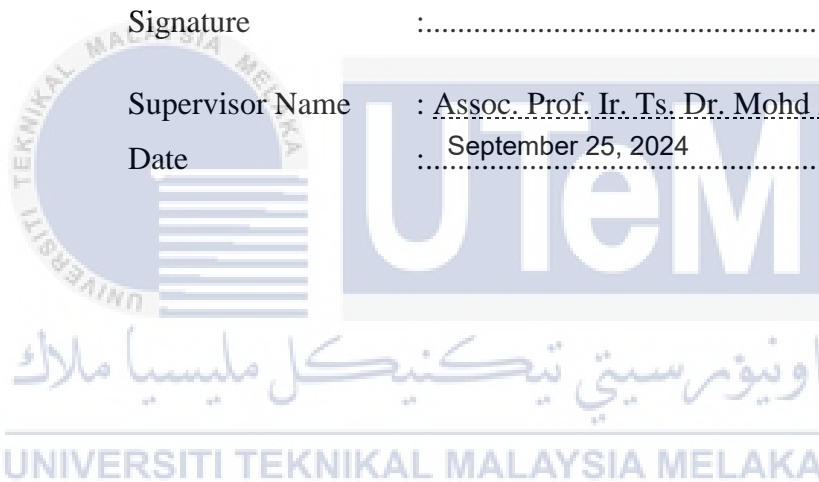
I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering.

Signature : .....

Supervisor Name : Assoc. Prof. Ir. Ts. Dr. Mohd Azli Bin Salim

Date : September 25, 2024

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## DEDICATION

To my beloved mother, father and most importantly my beloved wife.



## ABSTRACT

In a dynamic era characterized by the integration of innovation and technology, hybrid conductive ink has emerged as a powerful catalyst in the production of flexible electronic devices. It also opens up new opportunities to advance electronic printing technology. However, there are challenges in realizing it, namely in terms of formulating a suitable ink material for that purpose. Materials such as graphene nanoplatelets (GNP), which are carbon-based, become fillers in polymer composites together with silver flakes (Ag), planning a good combination with silver acetate (SA) to produce a new formulation of conductive hybrid ink. This research aims to study the characteristics and uses of GNP hybrid conductive ink when mixed with organic solvents and cured at 250°C. Several aspects have been studied as a research goal in terms of formulating a new GNP hybrid conductive ink formulation and further, comparing the characteristics of the new conductive ink formulation against the mechanical, electrical and morphological properties of the flexible substrate. The optimal formulation process of the hybrid conductive ink is important in ensuring its level of resistivity during cyclic testing using the Two-Point-Probe measurement technique. The evaluation of electrical and mechanical conductivity is started by carrying out a cyclic test on the sample and comparing it to the baseline, which is not subjected to the test. After the cyclic tests of torsion and bending are conducted, shear stress tests are also conducted to determine the mechanical properties. The reliability of the new formulation of conductive ink was also evaluated. After the cyclic and baseline tests, a comparative analysis of the GNP hybrid revealed no significant changes in the tested sample's resistivity. The total average resistivity of the sample was 1.99E-05  $\Omega\cdot\text{m}$  at baseline, and the lowest average for torsion was 2.02E-05  $\Omega\cdot\text{m}$  and for bending, 2.41E-05  $\Omega\cdot\text{m}$ . The higher shear stress values (MPa) for samples cured at 5 hours indicate a better result with an average of 57.36 MPa. The findings in this research show that the hybrid formulation of GNP in conductive ink can improve its electrical conductivity performance with an average improvement of 42.58% for both torsion and bending tests. This provides valuable insights, and pave the way for future improvements in conductive ink formulations that can be utilized in various flexible electronic applications.

## **KEBERKESANAN FORMULASI BAHARU DAKWAT KONDUKTIF HIBRID GNP/SA TERHADAP BEBANAN KITARAN KILASAN/LENTURAN**

### **ABSTRAK**

*Dalam era dinamik yang dicirikan oleh penyepaduan inovasi dan teknologi, dakwat konduktif hibrid telah muncul sebagai pemangkin berkuasa dalam pengeluaran peranti elektronik yang fleksibel. Ia juga membuka peluang baharu untuk memajukan teknologi percetakan elektronik. Namun begitu, terdapat cabaran dalam merealisasikan iaitu dari segi formulasi bahan dakwat yang sesuai bagi tujuan tersebut. Bahan seperti graphene nanoplatelets (GNP), yang berasaskan karbon, menjadi pengisi dalam komposit polimer bersama serpihan perak (Ag), merencanakan kombinasi yang baik dengan perak asetat (SA) untuk menghasilkan rumusan baharu dakwat hibrid konduktif. Penyelidikan ini bertujuan untuk mengkaji beberapa ciri dan kegunaan dakwat konduktif hibrid GNP apabila dicampur dengan pelarut organik dan diawet pada suhu 250°C. Beberapa aspek telah dikaji sebagai matlamat kajian dari segi merumuskan formulasi dakwat konduktif hibrid GNP baharu dan seterusnya, membandingkan ciri-ciri rumusan baharu dakwat konduktif terhadap sifat mekanikal, elektrik dan morfologi substrat fleksibel. Proses perumusan optimum dakwat konduktif hibrid adalah penting dalam memastikan tahap kerintangannya semasa ujian kitaran menggunakan teknik pengukuran kuar dua titik. Penilaian kekonduksian elektrik dan mekanikal dimulakan dengan menjalankan ujian kitaran pada sampel dan membandingkannya dengan garis dasar, yang tidak tertakluk kepada ujian. Selepas ujian kitaran kilasan dan lenturan dijalankan, ujian tegasan ricih juga dijalankan untuk menentukan sifat mekanikal. Kebolehpercayaan formulasi baru dakwat konduktif juga dinilai. Selepas ujian kitaran dan garis dasar, analisis perbandingan hibrid GNP mendedahkan tiada perubahan ketara dalam kerintangan sampel yang diuji. Jumlah kerintangan purata sampel ialah  $1.99\text{E-}05 \Omega.m$  pada garis dasar, dan purata terendah untuk kilasan ialah  $2.02\text{E-}05 \Omega.m$  dan untuk lenturan,  $2.41\text{E-}05 \Omega.m$ . Nilai tegasan ricih (MPa) yang lebih tinggi untuk sampel yang diawetkan pada 5 jam menunjukkan keputusan yang lebih baik dengan purata 57.36 MPa. Penemuan dalam penyelidikan ini menunjukkan bahawa formulasi hibrid GNP dalam dakwat konduktif boleh meningkatkan prestasi kekonduksian elektriknya, dengan purata peningkatan sebanyak 42.58% untuk kedua-dua ujian kilasan dan lenturan. Ini memberikan pandangan yang berharga, dan membuka jalan untuk penambahbaikan masa depan dalam formulasi dakwat konduktif yang boleh digunakan dalam pelbagai aplikasi elektronik yang fleksibel.*



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*In the name of Allah, The Beneficent, The Merciful*

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## LIST OF ABBREVIATIONS

|       |                                |
|-------|--------------------------------|
| RFID  | Radio frequency identification |
| PCB   | Printed circuit boards         |
| GNP   | Graphene nanoplatelets         |
| Au    | Aurum (Gold)                   |
| Pt    | Platinum                       |
| AgNPs | Silver nanoparticles           |
| CNT   | Carbon nanotube                |
| CPs   | Conductive polymers            |
| Cu    | Copper                         |
| Ag    | Silver                         |
| Al    | Aluminium                      |
| SA    | Silver acetate                 |
| PE    | Printed electronics            |
| DMF   | Dimethylformamide              |
| NMP   | N-methyl-2-pyrrolidone         |
| SEM   | Scanning Electron Microscopy   |
| EDX   | Energy Dispersive X-ray        |

|           |   |
|-----------|---|
| IACS      | International Annealed Copper Standard                    |
| PTF       | Polymer thick films                                       |
| Zn        | Zinc  |
| CVD       | Chemical vapor deposition                                 |
| 3D        | Three-dimensional   |
| CFD       | Computational fluid dynamics                              |
| PEDOT:PSS | Poly (3,4-ethylenedioxythiophene)-poly (styrenesulfonate) |
| DoD       | Drop-on-demand  |
| PET       | Polyethylene terephthalate                                |
| AgNW      | Silver nanowires  |
| SCI       | Stretchable conductive ink                                |
| PD        | Palladium   |
| Sn        | Tin   |
| CB        | Carbon black  |
| RPM       | Revolutions per minute                                    |
| SE        | Secondary electron  |
| IoT       | Internet of things  |
| Gr-Ag     | Graphene - silver   |
| GNP-Ag    | Graphene nanoplatelets and silver                         |

|          |                           |
|----------|---------------------------|
| xGnP H-5 | GNP powder                |
| wt. %    | Weight percentage         |
| $R_m$    | Material resistance       |
| UTM      | Universal Testing Machine |



## LIST OF SYMBOLS

|                      |                              |
|----------------------|------------------------------|
| $\Omega \cdot m$     | Ohm meter                    |
| %                    | Percentage                   |
| $k\Omega/sq$         | kiloohms per square          |
| \$                   | Dollar                       |
| $^{\circ}C$          | Degree Celsius               |
| $\Omega \cdot cm$    | Ohm centimeter               |
| $\mu m$              | Micrometer                   |
| $\mu\Omega \cdot cm$ | Microohm centimeter          |
| $R, \Omega$          | Resistance                   |
| $V$                  | Voltmeter                    |
| $I$                  | Current source to the sample |
| $M\Omega$            | Megaohm                      |
| $V_s$                | Voltage source               |
| $I_m$                | Current measure              |
| $\rho$               | Volume of resistivity        |
| $A$                  | Cross-sectional area         |
| $L$                  | Length                       |
| $F$                  | Force                        |
| $\ell$               | Length of the specimen       |
| $w$                  | Width of conductive ink      |
| $t$                  | Thickness of conductive ink  |

|          |                        |
|----------|------------------------|
| $x$      | Zoom ratio of the lens |
| $E$      | Young's modulus        |
| $\tau$   | Shear stress           |
| $\sigma$ | Stress                 |

