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# Experimental Investigation for Gauge Factor of Carbon Nanotube Strain Sensor

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***Abstract***
*Sensors remain to play crucial role in our daily life. There is an increase in the need for manufacturing highly precise, active and worthwhile sensors. Consequently, research prominence is in the process of developing modern sensing resources and technologies. Carbon Nanotubes (CNTs) possess several distinctive properties that will be used to further develop the forthcoming creation of sensors and technologies. Excellent mechanical, electrical and electromechanical properties of Carbon Nano Tubes (CNT) encompass lot of novel applications. The demand for high-flexibility, high-sensitivity strain gauges that can detect tiny deformations and vibrations in intense conditions is growing. Due to their large gauge factor, multi-directional sensing abilities, high flexibility, high active range, and high sensitivity to strains at the nanoscale, carbon nanotube strain sensors are becoming popular. Also, the electrical characteristic like resistivity of carbon nanotube sensor varies in a linear fashion in relation to the amount of strain, creating it a perfect resource for strain measurements. In the present investigation, carbon nanotube strain sensor was successfully fabricated by screen printing process. Experimentally, a high gauge factor of CNT strain sensor was obtained. Also presented the relationship between load Vs strain and resistance of CNT strain sensor as a straight line. The investigational results proved that the CNT strain gauges have higher nominal resistance, gauge factor than conventional strain sensors.*
***Keywords:*** *CNT, Fabrication, Gauge factor, Screen printing, Strain sensor, Thin film*

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## I. INTRODUCTION

High-flexibility, high-sensitivity, low-power strain gauges able to sense minor deformations and vibrations in intense environments are in high demand. The advancement of technology in the field of nanotechnology allows promising possibilities for new sensors, which plays a key role. Carbon nanotubes (CNTs) offer a variety of unique features that can be used to create the next generation of sensors [1]. Carbon nanotubes (CNTs) are tubes made of carbon with diameters typically measured in nanometers. It is having the properties like high aspect ratio, very high tensile strength, low thermal expansion coefficient. [2]. In both the academic and industrial worlds, carbon nanotubes (CNTs) have gained a lot of attention because of their exceptional mechanical, electrical as well as thermal capabilities [3,24].

Integration of CNT reinforcements into polymers allows the production of polymer matrix composites which exhibits elevated mechanical performance and outstanding functionality [4]. Because of their electrical characteristics and strong mechanical strength, carbon nanotubes could be used as a strain sensor [3,26]. Strain measurements are an exciting subject of engineering and academic study for detecting and depicting structural deterioration. Low gauge resistance, tiny gauge factor, and temperature-dependent drift are some of the drawbacks of foil strain gauges. The gauge factor, gauge size, and gauge resistance are all critical for achieving great resolution and low power dissipation [4,23]. Carbon nanotubes (CNTs) have discovered as revolutionary material for making strain sensors to conquer the limits of metal foil-type gauges due to their improved electromechanical capabilities. [5-12]. Individual single-walled carbon nanotubes (SWCNTs) and multi-walled carbon nanotubes (MWCNTs) are shown to have remarkable piezoresistive capabilities, suggesting that CNTs could be used as strain sensors. [5,11]. Carbon nanotube thin film strain sensors, which can be implanted into the structural materials with exceptional strain sensitivity at the nanoscale. [13,25]. Traditional foil-type gauges have lower gauge factors than these strain sensors. When compared to metal foil strain gauges, which have a gauge factor of roughly two, CNT strain gauges have a substantially higher gauge factor[5,26]. Developing strain sensors with a high gauge factor remains as a greatest challenge.

W.Wang, K.Liao and the team has experimentally determined carbon nanotube thin film piezo-resistive effect. The strain sensor's gauge factor was discovered to be 65 [14]. Peng Zhang carried out investigation of nano strain gauges and found the gauge factor value maximum 61.82 [15].

D.Lee used a spray coating approach to create a carbon nanotube strain gauge. In this experiment, the maximum gauge factor obtained was 6.42. [16]. In their batch fabricated SWCNT strain sensors clearly shows resistance variations and applied strain have a linear relationship. While the previous researchers investigated the various values of gauge factor of nanostrain sensor. Hence, an attempt is made to design a CNT strain gauge which is having high gauge factor than the previous results.

In this research, we present the design, development, fabrication of high accuracy strain gauges made up of carbon nano tube film along with kapton polymer. To explore the strain gauge factor, the CNT strain gauge was subjected to a load test. The findings of the study revealed that the CNT strain gauges have high nominal resistance in the order of Kilo ohm and gauge factor value is 95.64. Also it is having linear relationship between applied load, strain and resistance difference.

## II. STRAIN GAUGE CONCEPTS

A strain gauge is a type of sensor which is used to measure force or strain, pressure, weight and tension. Very thin wire or metallic foil is put in a grid pattern on the metallic strain sensor [17]. The strain gauge resistance varies with applied strain in the material. When the material expands, ie in tension mode, its resistance increase and when the material contracts, ie in compression mode, its resistance decrease. Based on the resistance change, its electrical output will vary [18].

### 2.1 Carbon Nanotube strain sensors

CNTs are regarded as a elegant source for fabrication of strain sensors, since their electrical characteristics are dependent on mechanical deformation. [19]. Fig.2 illustrates the basic working principle of Carbon nanotube strain sensors. Let us consider the initial resistance of CNT network is $R_0$. When they are extended, the base resistance increases to R0 + R (R is the resistance change). When the strains are relaxed, the CNT network returns to its original location, resulting in R0 resistance [20].

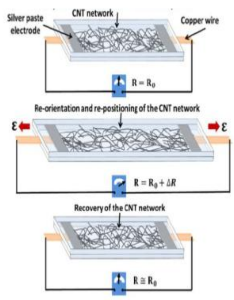


**Figure.1** CNT strain gauge working principle

## III. MATERIALS AND METHODS

CNT strain gauges were fabricated by Screen printing technology.

### 3.1 Screen printing process

It is an inexpensive process, extensively used in electronics manufacturing, especially in the production of sensors. A conductive paste based on a polymeric binder containing metallic dispersions is utilized for the deposition of successive layers. Stabilizers, cofactors, and mediators are among the functional materials they contain [20].

Screen printing is a quick and easy procedure that involves squeezing metallic paste through a patterned screen onto a substrate held on the screen's backside.

This process can deposit multiple layers at once, and repetitive designs can be generated on the same screen to increase manufacturing speed. PVC, polycarbonate, polyester, ceramic, and glass fibers are the most widely utilized substrates. Specific pattern can be developed by depositing each layer through the corresponding mask.

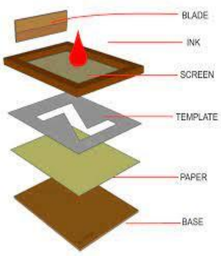


**Figure.2** Screen printing technology

### 3.2 Fabrication process

The following diagram shows the fabrication process of CNT strain gauges. The CNT paste was first loaded onto screen meshes on kapton polymer substrate and squeezed. After that, the printed patterns were dried in a 70°C oven for one hour. The two ends of the sensor are coated with silver paste electrodes to ensure electrical connection. Then it was cured again at 70°C for about 2 hours. After that, with the help of coating machine, parylene coating was applied for sensor protection.

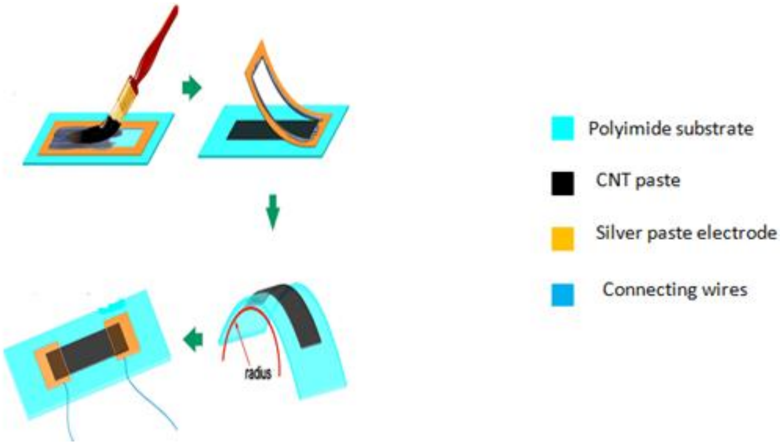


**Figure.3** CNT strain gauge fabrication process

*3.2.1 Conductive Adhesive:*

It's usually industrial-grade, and it's manufactured from a unique blend of components developed expressly for the purpose of creating electrically conductive glue. It's mostly utilised to turn an insulative surface into a conductive one. It's represented by the letter (Ag), which stands for silver's molecular or linear formula. It is naturally electrically and thermally conductive. The adhesion of the Silver paste is quite high, thus it sticks to almost any surface. It quickly becomes dry due to its volatile solvent base [20]. The CNT conductive paste are designed to be a high performance conductive additive for various sensor applications. The CNT conductive paste comprise of highly dispersed carbon nanotubes in N-methyl-2-pyrrolidone (NMP) with additives [21].

*3.2.2 Parylene coating*

Parylene (poly paraxylylene) is a generic name for polymers which belongs to a unique chemical family. They are used as a conformal coatings in protective applications. These coatings are formed by the polymerization of para-xylene, which are deposited on the substrate by vacuum deposition. Since it is applied as a vapor, the coated layer provides complete and even coverage. Thus the coating is uniform, thin, stress free and has a excellent mechanical properties. [22].

### 3.3 Bonding of strain gauges

After preparation of CNT strain gauges, these are bonded to metal specimen which is made up of SS 304. A CNT strain gauge has been over the left side of metal specimen and for reference, a metal foil strain gauge was glued to the right side. With adhesive, copper wires of 1 mtr length were joined to the two ends of the strain sensor. Before being subjected to load test, measured nominal resistance of CNT strain gauge and metal foil strain gauge are 26.010 KΩ and 350.05 Ω respectively.

**Figure.4** Metal specimen

**Figure.5** CNT strain gauge

**Figure.6** Metal foil strain gauge

## IV. MORPHOLOGY

Under a 10kV accelerating voltage, scanning electron microscopy was employed to study the morphology of the CNT strain sensors. The SEM images at low and high resolution are shown in the diagram below.

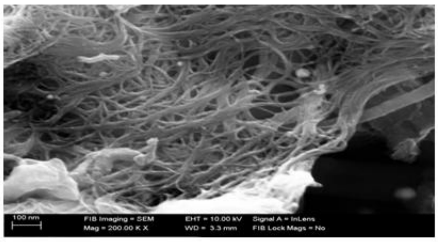

**Figure.7** Low resolution SEM image

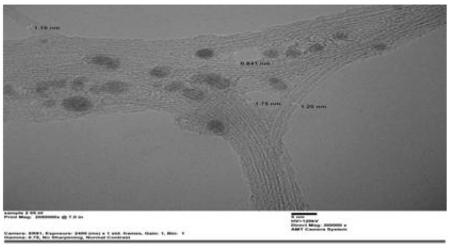

**Figure.8** High resolution SEM image

## V. EXPERIMENTAL

To evaluate the gauge factor of strain sensors and the influence of applied strain on the produced strain sensors, used an Universal Testing Machine (UTM) to perform load tests up to 550 Kgf in 20 Kgf increments. The resistance of strain sensors was measured using a 6 1/2 digit digital multimeter during the load test. Load and strain values are acquired by UTM software.

**Figure.9**
Test setup

**Figure.10**
Data acquisition

**Figure.11**
Resistance measurement

### 5.1 Test Results

The data acquired through UTM software and digital multimeter is analyzed in order to found the gauge factor, resistance variation and relationship between load & strain. From the test data, calculated gauge factor is,

$$GF = \Delta R/R \ / \ \Delta L/L = 0.45163 / 0.004722$$

Gauge Factor = 95.64

### 5.2 Data plots

From the above test results, for all load values, electrical resistance and strain increases linearly with applied load. This excellent linearity is crucial importance for accurate sensing. The data plots exhibits the linear correlation between load, resistance, change in resistance and strain.

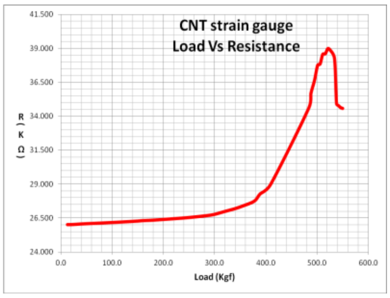


**Figure.12** Load Vs Resistance of CNT strain gauge

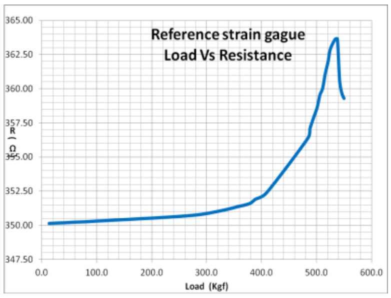


**Figure.13** Load Vs Resistance of Reference strain gauge

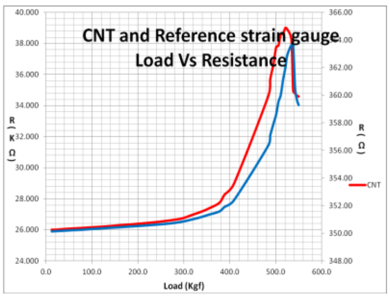


**Figure.14** Load Vs Resistance of both gauges

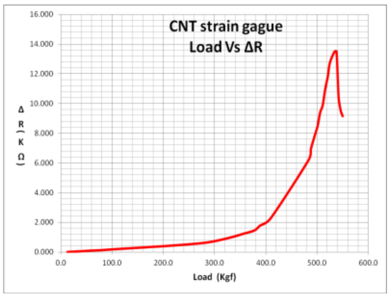


**Figure.15** Load Vs ΔR of CNT strain gauge

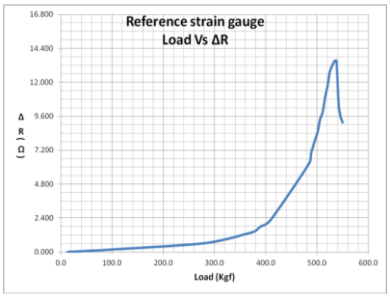


**Figure.16** Load Vs ΔR of Reference strain gauge

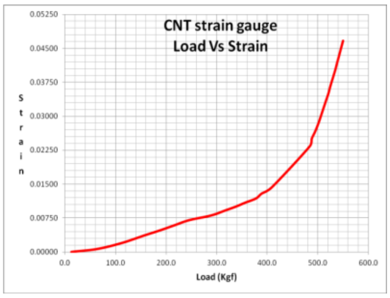


**Figure.17** Load Vs Strain of CNT strain gauge

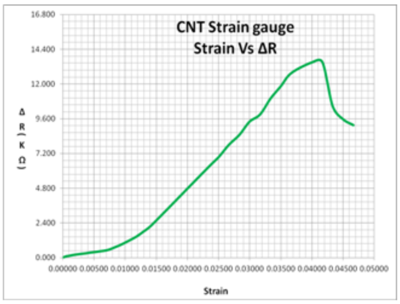


**Figure.18** Strain Vs ΔR of CNT strain gauge

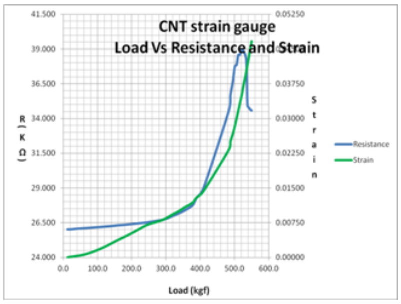


**Figure.19** Load Vs Resistance and Strain of CNT strain gauge

### 5.3 Data Analysis

The test results were analyzed and found the following. Gauge factor of developed CNT strain gauge fabricated by screen printing process is experimentally investigated as 95.64. The nominal resistance of CNT strain gauge is higher than conventional metal foil strain sensors. The resistance change (ΔR) value is high when compared to metal foil strain sensors. The variation in resistance and strain value are linearly varies with applied load.

## VI. CONCLUSION

Designed, developed & fabricated carbon nanotube based strain sensor by screen printing process. Material characterization was done by load test with Universal Testing Machine (UTM). Acquired test data and analyzed the test results. Investigated high gauge factor of CNT strain gauges as 95.64. In particular the sensor come out with a stable resistance change under load conditions, demonstrating its feasibility for sensing applications.

### FUTURE SCOPE

Designing of load cell with the developed strain sensor as the sensing element. Design & development of load cell electronics with analog and digital outputs. Design of load cell package with integrated electronics. Carry out load test with various known loads. Based on the results, fine tuning of electronics has to be carried out. Also actual trials with accurate load measurement have to be carried out.

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