# Experimentation and Simulation of PDMS-CNT Nanocomposite Based Flexible Strain Sensor

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*Abstract:* Carbon Nanotubes (CNTs) have impressive electrical, electromechanical and mechanical properties, these properties promoted to a lot of applications. The composites of CNT with polymers have potential applications in strain sensors. The paper discusses the preparation of CNT film by using Vacuum filtration method and preparation of composite by Sandwich method which is used to fabricate the sensor structures using CNT and PDMS films. Bending test was performed with CNT-PDMS based sensors, which are bonded on Aluminum plate. These studies demonstrated the effect of aspect ratio on sensitivity of CNT-PDMS sensor and Simulation was performed using COMSOL Multiphysics 5.3a software. It was found that CNT-PDMS strain sensor shows linear relationship between change in resistance and applied strain. The gauge factor and initial resistance of sensor increases as the CNT film aspect ratio increases.

***IndexTerms*– Polydimethylsiloxane, CNTs, Sensitivity, Strain Sensor, COMSOL Multiphysics.**

## I. INTRODUCTION

Carbon nanotubes are made of carbon molecules organized in rolled up structures. They are cylindrical elongated structures. These are further classified as single walled carbon nanotubes (SWCNTs) and multi walled carbon nanotubes (MWCNTs) as shown in Fig.1. Geometry of CNTs is important as the properties of CNTs are concerned. Carbon nanotubes are electrically conductive and helpful for enhancing polymer properties. In recent years, many researchers have shown that carbon nanotubes have unique nanostructure and excellent mechanical and physical properties. They are widely used to improve electrical, thermal and optical properties of polymer composites. However, the successful usage of the properties of nanotube composites depends on the quality of their dispersion in the Nanocomposites [1].

Conducting polymers have discovered an extensive variety of utilizations in the different fields of energy devices, medicine, actuators, electronics, optics and composites as a practical contrasting option to metallic or inorganic semiconductor parts. Specifically, there has recently been huge demand for developing flexible or wearable electronics, displays, and other devices, in which conducting polymers are used [2].

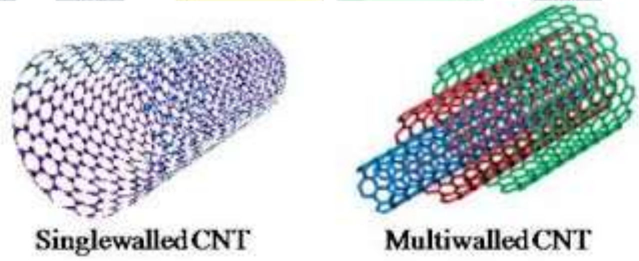


Figure 1 single walled and multi walled carbon nanotubes

### 1.1 Origin of problem

These composite sensors have a wide range of advantages compared to other sensors like high sensitivity, flexibility. Stretchable sensor applications include large scale neuron sensor networks on humans, engineering structures etc [3]. Even though commercially available strain sensors based on metal foils and semiconductors have a well-established technology and low cost of fabrication, they possess very poor stretch ability.

Hence there is a need to develop sensors with higher sensitivity and which can be embedded in the structure to offer additional functionality like structure strengthening and good stretch ability. Use of Nanocomposites as sensors can fulfil these promises.

### 1.2 CNT-polymer Nanocomposites

Conducting polymer Nanocomposites typically consist of conducting fillers are incorporated in a polymer matrix. These multifunctional materials have lot of applications that include electrostatic dissipation, electromagnetic interference shielding and heat dissipation. Carbon nanofillers, for example, carbon dark and carbon nanotubes are electrically conductive and valuable for enhancing polymer properties [4].

Research on different polymers were done till date including eco-flex, polyurethane, polyethylene, epoxy, polyamide and polycarbonate etc. These composites are utilized as a part of numerous fields like defense, aerospace, electronics and data storage etc [2].

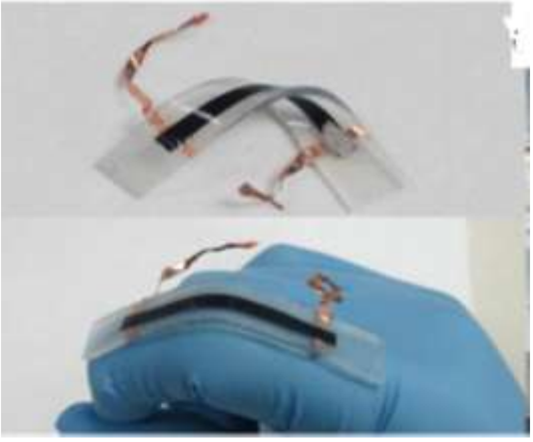

Figure 2 Flexible CNT-Polymer Sensors [5]

## II. PREPARATION OF SENSOR

### 2.1 Preparation of CNT Films

A 25 mg of MWCNT was mixed in 100 ml of Dimethylformamide (DMF) solvent. DMF MWCNT solution was then ultra sonicated in a bath sonicator (DC80H, MRC, 80 W) for 3 hours and by an ultrasonic tip (VibraCell VCX130) for 20 min in an alternating sequence.

CNT suspension was then filtered by using vacuum filtration method. The film is peeled off from filter paper and dried in an oven at $80^0$ C for 12 hours [5]. The film after drying is cut in required aspect ratios.

Figure 3 CNT film

### 2.2 Fabrication of Specimens

In this method simple three layers composite considered for the strain sensors. Out of three two layers of PDMS and one is of CNT. Composite consist of CNT thin films laminated between the top and bottom layers of PDMS. Initial resistance of the strain sensors is increases when the strain sensors are stretched out and this result re-orientation and re-positioning of CNTs within a network [6].

The CNT-PDMS strain sensor is bonded on aluminium strip by epoxy adhesive. The terminals for the electrical resistance measurements were taken from film through silver paste.

Figure 4 Bending test specimen

## III. EXPERIMENTATION

The aluminum strip on which sensor specimen are bonded is subjected to bending loading. Corresponding resistance change is measured with a multimeter.

### 3.1 Bending Test Setup

The setup consists of Frame which is fixed by using clamp and on frame Aluminium Plate is clamped for loading (100gm - 1000gm) of specimens and digital multimeter for measuring the resistance change. The CNT-PDMS strain sensors are bonded on aluminium plate (300mm×30mm×5mm) by epoxy adhesive.

Figure 5 Bending test set up

### 3.2 Strain and gauge factor calculation

For the three specimens, readings of change in resistance are taken for loading from 100gm to 1000gm at free end of cantilever beam. Then the Strain induced in cantilever beam is calculated by bending equation.

Bending equation is,

$$\frac{\sigma}{y} = \frac{M}{I} \quad (3.1)$$

$$gauge\ factor = \frac{Relative\ change\ in\ resistance}{Applied\ strain} = \frac{\left(\frac{\Delta R}{R}\right)}{\epsilon} \quad (3.2)$$

Where,

ΔR = is the change in resistance caused by strain,

R= is the resistance of the undeformed gauge, and

ε = is strain.

For every specimen, strain and gauge factor is calculated as follows:

1) Specimen No 1

Initial Resistance=959.5 ohm, Aspect ratio=6

Table 1 Gauge factor of Specimen No-1

| Sr. No. | Weight (gm) | Weight (N) | M | Z | Bending stress(N/mm$^2$) | Micro strain | R(ohm) | ΔR | Relative change in resistance |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 100 | 1 | 082 | 125 | 0.656 | 09.24 | 959.6 | 0.1 | 0.000104 |
| 2 | 200 | 2 | 164 | 125 | 1.312 | 18.48 | 959.9 | 0.4 | 0.000417 |
| 3 | 300 | 3 | 246 | 125 | 1.968 | 27.72 | 960.2 | 0.7 | 0.000729 |
| 4 | 400 | 4 | 328 | 125 | 2.624 | 36.96 | 960.4 | 0.9 | 0.000937 |
| 5 | 500 | 5 | 410 | 125 | 3.280 | 46.20 | 960.8 | 1.3 | 0.001353 |
| 6 | 600 | 6 | 492 | 125 | 3.936 | 55.44 | 961.0 | 1.5 | 0.001561 |
| 7 | 700 | 7 | 574 | 125 | 4.592 | 64.68 | 961.1 | 1.6 | 0.001665 |
| 8 | 800 | 8 | 656 | 125 | 5.248 | 73.92 | 961.3 | 1.8 | 0.001872 |
| 9 | 900 | 9 | 738 | 125 | 5.904 | 83.15 | 961.5 | 2.0 | 0.002080 |
| 10 | 1000 | 10 | 820 | 125 | 6.560 | 92.39 | 961.7 | 2.2 | 0.002288 |

Similarly, Strain and gauge factor calculated for Specimen No 2 and 3 as shown table 2 and 3.

2) Specimen No 2
Initial Resistance=255 ohm, Aspect ratio=4

Table 2 Gauge factor of Specimen No-2

| Sr. No. | Weight (gm) | Micro strain | R (ohm) | Relative change in resistance |
|---|---|---|---|---|
| 1 | 100 | 10.14 | 255.05 | 0.00020 |
| 2 | 200 | 20.28 | 255.11 | 0.00043 |
| 3 | 300 | 30.42 | 255.14 | 0.00055 |
| 4 | 400 | 40.56 | 255.19 | 0.00074 |
| 5 | 500 | 50.70 | 255.25 | 0.00098 |
| 6 | 600 | 60.85 | 255.28 | 0.00110 |
| 7 | 700 | 70.99 | 255.32 | 0.00125 |
| 8 | 800 | 81.13 | 255.45 | 0.00176 |
| 9 | 900 | 91.27 | 255.59 | 0.00231 |
| 10 | 1000 | 101.41 | 255.67 | 0.00262 |

3) Specimen No 3
Initial Resistance=50.05 ohm, Aspect ratio=2

Table 3 Gauge factor of Specimen No-3

| Sr. No. | Weight (gm) | Micro strain | R(ohm) | Relative change in resistance |
|---|---|---|---|---|
| 1 | 100 | 21.07 | 50.08 | 0.000599 |
| 2 | 200 | 42.14 | 50.10 | 0.000998 |
| 3 | 300 | 63.21 | 50.13 | 0.001596 |
| 4 | 400 | 84.28 | 50.15 | 0.001994 |
| 5 | 500 | 105.35 | 50.17 | 0.002392 |
| 6 | 600 | 126.42 | 50.19 | 0.002789 |
| 7 | 700 | 147.49 | 50.21 | 0.003187 |
| 8 | 800 | 168.56 | 50.22 | 0.003385 |
| 9 | 900 | 189.63 | 50.24 | 0.003782 |
| 10 | 1000 | 210.70 | 50.25 | 0.003980 |

## IV. Finite Element Analysis

In this work, finite element analysis based simulation was carried out using COMSOL Multiphysics software 5.3a version. The simulation of CNT-polymer based gauge and hence computed for gauge factor.

### 4.1 Building the geometric model

According to dimensions of CNT-PDMS NanoComposite, the sensor is modelled in Catia V5R20. Now this strain sensor is placed on an aluminium strip which is considered as a cantilever beam. A perfect surface contact is assumed between the two surfaces. The assembly of this structure was done in Catia V5R20.

### 4.2 Defining physics and boundary conditions

To perform the simulation correctly, there are two steps which are defining the physics and setting up boundary conditions. Boundary conditions for solid mechanics and electric currents modules are setup separately, after choosing the physics. In solid mechanic's module, a fixed constraint is defined to fix the cantilever on one end and the application of point load on the free end of the cantilever.

In electric currents module, one of the contact pads, of the sensor, in grounded and the terminal boundary condition is assigned to the other contact pad. The boundary surface between the strain sensor and the cantilever beam is electrically insulated. These point loads applied at free end can be varied by using parametric sweep function [1].

### 4.3 Simulating the model

This simulation mainly utilized solid mechanics and electric current modules, a plot of stress vs electric potential is plotted as the output.

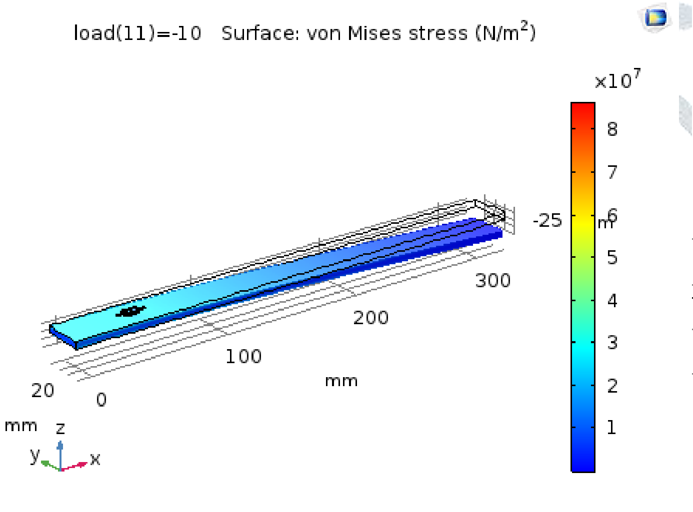


Figure 6 Stress plot

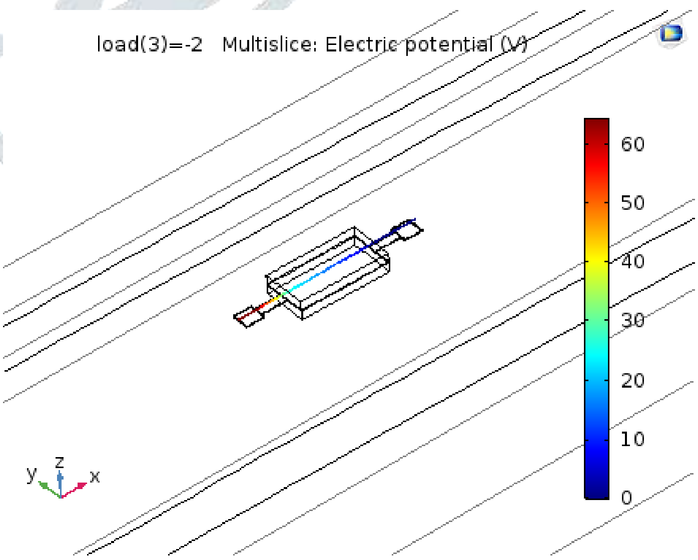


Figure 7 Distribution of electric potential

## IV. RESULTS AND DISCUSSION

### 4.1 Experimental Results

The relative change in resistance with respect to applied strain for three CNT-PDMS film sensors, Sensor 1 to 3 gauges applied on aluminum strip is shown in Fig's.

Gauge factor is slope of straight line fitted in the graphs shown in Fig.8, Fig.9 and Fig.10. The gauge factors were determined for all these three sensors using equation (3.2) i.e. slope of straight lines fitted are listed in Table. The graph of Relative change in resistance vs strain is shown in figs.8 to 10.

Table 4 Experimental Results

| Sr. No. | Aspect Ratio | Experimental | |
|---|---|---|---|
| | | Initial Resistance (ohm) | Gauge factor |
| 1 | 6 | 959.5 | 25.846 |
| 2 | 4 | 255.0 | 25.501 |
| 3 | 2 | 50.05 | 18.074 |

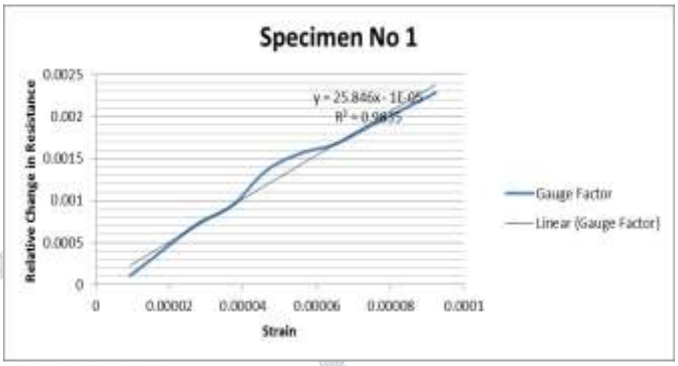


Figure 8 Gauge factor of specimen No 1

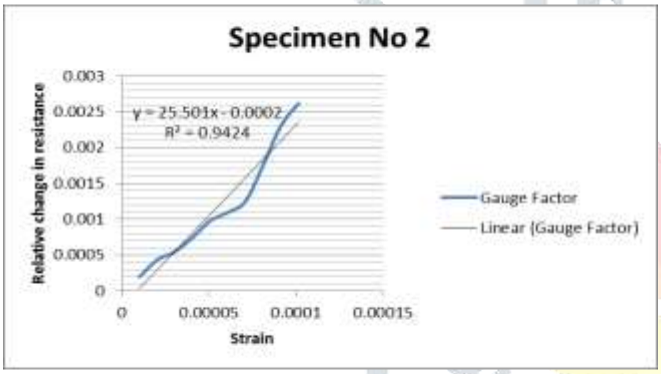


Figure 9 Gauge factor of specimen No 2

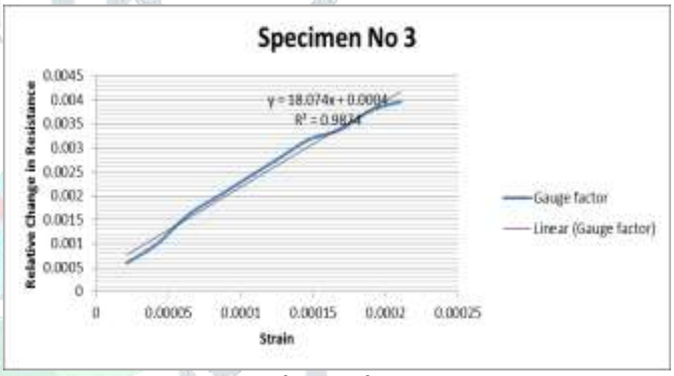


Figure 10 Gauge factor of specimen No 3

### 4.2 Finite element Analysis Results

The relative change in resistance with respect to applied strain for three CNT film sensors determined by FEM analysis in COMSOL is shown in Table 4 and graphs in Fig.11 to 13.

Table 4 Finite element Analysis Results

| Sr. No. | Aspect Ratio | Finite element Analysis | |
|---|---|---|---|
| | | Initial Resistance (ohm) | Gauge factor |
| 1 | 6 | 853.8033103 | 6.119 |
| 2 | 4 | 245.1214638 | 2.999 |
| 3 | 2 | 98.0299598 | 1.530 |

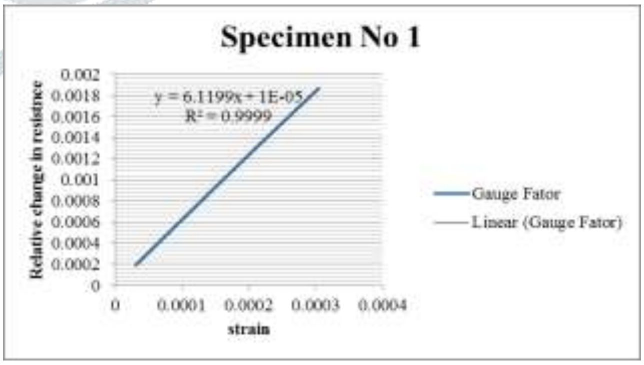


Figure 11 Gauge factor of specimen No 1 from FEA

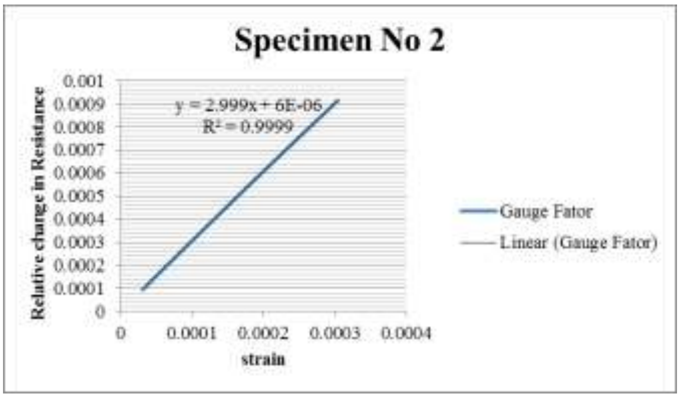


Figure 12 Gauge factor of specimen No 2 from FEA

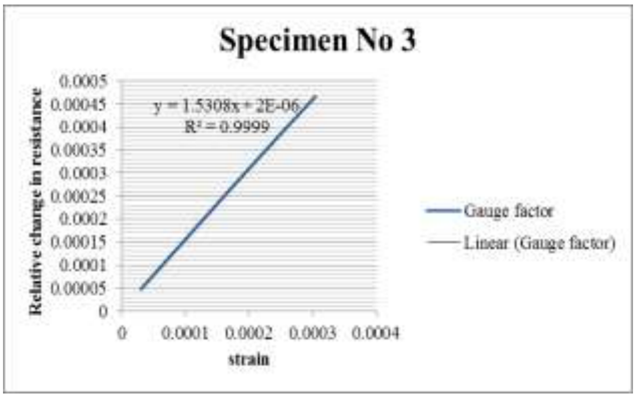


Figure 13 Gauge factor of specimen No 3 from FEA

Results of Initial resistance and gauge factor obtained are compared with Finite element Analysis. It was found that good agreement with experimental results as shown in Fig.14 and Fig.15.

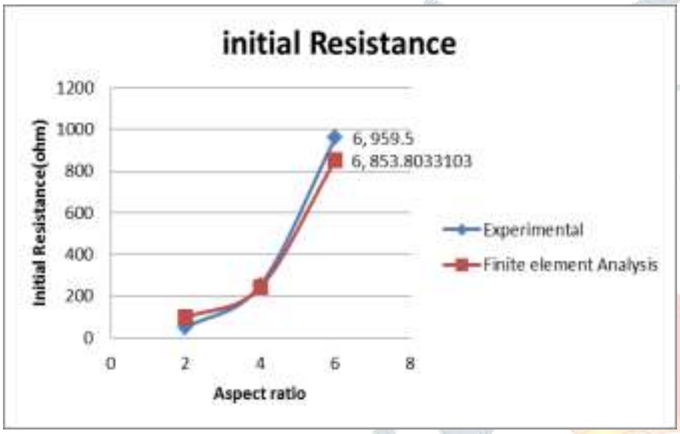


Figure 14 Comparison of initial resistance

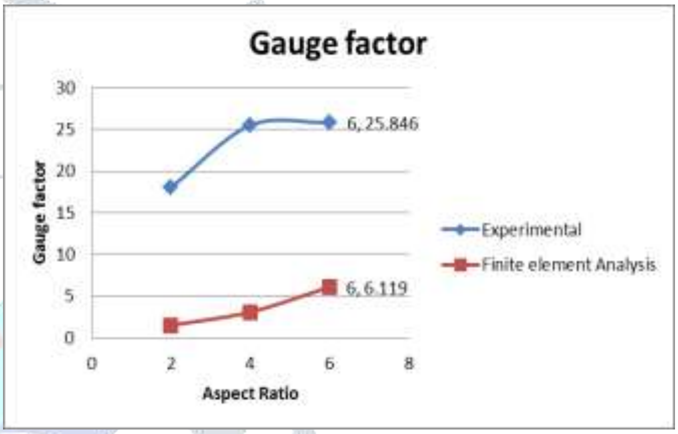


Figure 15 Comparison of gauge factor

In order to check effect of Aspect ratio on Initial resistance and gauge factor, simulation is carried out on different size CNT films. Fig.16 and Fig. 17 shows initial resistance and gauge factor increase as aspect ratio increases.

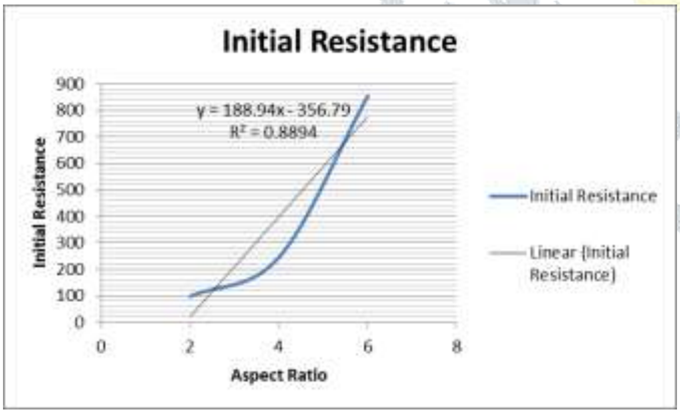


Figure 16 Effect of aspect ratio on initial resistance

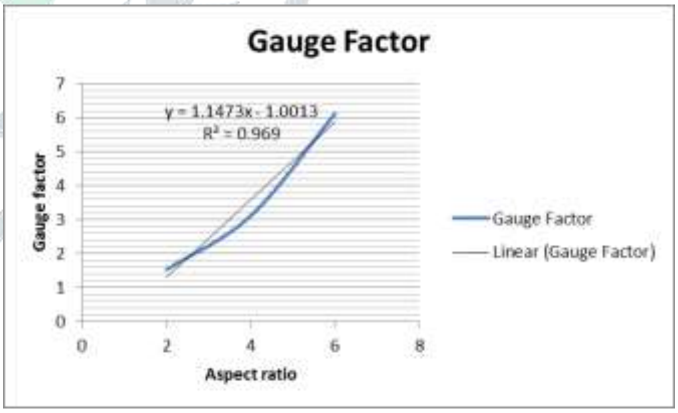


Figure 17 Effect of aspect ratio on gauge factor

## V. CONCLUSION

In this paper, the effect of Aspect ratio on Sensitivity of the CNT-PDMS Nanocomposite was studied. COMSOL Multiphysics software was observed to be the best tool to analyze strain sensing films. The Nanocomposite strain sensor is analyzed by using its properties from the literature and observed that the values are in agreement with the values from the experimentation.

1. CNT-PDMS film sensors show nearly linear response to applied strain similar to conventional metal foil gauges.
2. Initial Resistance of CNT-PDMS film sensor is depends on aspect ratio. Initial resistance increases with increasing Aspect ratio.
3. Gauge factor of CNT-PDMS film sensor is affected by aspect ratio. Higher aspect ratios were shown to result in better sensitivity.

## REFERENCES


[1] Nagendra Krishna Chaitanya Tummalapalli. Experimental Characterization and Simulation of Carbon Nanotube Strain Sensing Films. Western Michigan University, 12-2016.

[2] Yoon, H. (doi: 10.3390/nano3030524.). Current Trends in Sensors Based on Conducting Polymer Nanomaterials. Nano materials 2013, 524-549.

[3] Gupta, N. (July 2006). Advances in sensors based on conducting polymers. Journal of Scientific & Industrial Research Vol. 65, 549-557.

[4] Milo S.P. Shaffer, J. K. Carbon Nanotube/Nano fibre Polymer Composites. Germany: Imperial College London.

[5] Khodke, M. (August 2016). An investigative study on application of carbon nanotubes for strain sensing. https://www.researchgate.net/publication/307142725, 755-758.

[6] Morteza Amjadi, Y. J. (25 August 2015). Ultra-Stretchable and Skin-Mountable Strain Sensors Using Carbon Nanotubes–Ecoflex Nanocomposites. IOP Publishing Ltd.

[7] Rajarajan Ramalingame, P. C. (Proceedings 2017, 1, 384; doi: 10.3390/proceedings1040384). Investigation on the Influence of Solvents on MWCNT-PDMS Nano composite Pressure Sensitive Films.

[8] Reddy, B. R. (2016). Modelling and Simulation of Nano and Multiscale Composites. Visakhapatnam - 530 003, India: College of Engineering, Andhra University.