A Project Report

On

CNT REINFORCED SENSORS FOR STRAIN/DAMAGE EVALUATION

BY

M.GANESH KUMAR 15XJ1A0121

N SAI KIRAN 15XJ1A0138

P GYANPRAKASH REDDY 15XJ1A0141

Under the supervision of

DR. MOHD ATAHULLAH KHAN

DR. ARUN NARAYAN

SUBMITTED IN PARTIAL FULLFILLMENT OF THE REQUIREMENTS OF

SE 421: PROJECT TYPE COURSE

MAHINDRA ECOLE CENTRALE

COLLEGE OF ENGINEERING

HYDERABAD

(DECEMBER 2018)

ACKNOWLEDGEMENTS

We would like to express special thanks of gratitude to DR.Mohd Ataullah Khan and DR.Arun Narayan who gave us this opportunity to do this project on the CNT reinforced sensors which is used in structural health monitoring.

Mahindra Ecole Centrale

Hyderabad

Certificate

This is to certify that the project report entitled "**CNT reinforced sensors for strain/damage evaluation**" submitted by M.Ganesh Kumar (ID No. 15XJ1A0121), N.Sai Kiran (ID No. 15XJ1A0138) and P.Gyanprakash Reddy (ID No. 15XJ1A0141) in partial fulfillment of the requirements of the course SE421, Project Course, embodies the work done by him/her under my supervision and guidance.

(SUPERVISOR NAME & Signature)

Mahindra Ecole Centrale, Hyderabad.

Date:

(EXTERNAL NAME & Signature)

Mahindra Ecole Centrale, Hyderabad.

Date :

ABSTRACT

The aim of this research project is to fabricate self-sensing nanocomposites based on carbon nanotubes (CNTs). We aim to fabricate the polymers with different weight percentages of CNTs. This report shows various techniques of fabrication and literature study of different papers where they demonstrated fabrication of low cost, self-sensing nanocomposites for potential use in structural health monitoring.

CONTENTS

CHAPTER 1
STRUCTURAL HEALTH MONITORING

All structures, including critical civil infrastructure facilities like bridges and highways, deteriorate with time. This deterioration is due to various reasons including fatigue failure caused by repetitive traffic loads, effects of environmental elements, and extreme events such as an earthquake. If the damages remain undetected, the structure may have a reduced margin of safety or have serviceability problem. Consequently, the integrity of the structural systems have high probability of a collapse, resulting in loss of life and property. Increasing concern about the status of existing structures, particularly after earthquakes, has motivated numerous studies on damage detection using various non-destructive evaluation methods.

Structures such as tall buildings, bridges and dams , have to be maintained against various factors such as deterioration, excessive loads, environment, temperature etc. Choosing an appropriate monitoring system is important for determining any critical damage to a structure and address that to avoid any adverse consequence. Structural Health monitoring has emerged as an effective method to evaluate the health or monitor the health of the structure.

Structural health monitoring (SHM) is the process of implementing a damage detection strategy. This process involves the observation of a structure over a period of time using periodically spaced measurements, the extraction of features from these measurements, and the analysis of these features to determine the current state of health of the structural system. The output of this process is periodically updated information regarding the ability of the structure to continue to perform its desired function in light of the inevitable aging and degradation resulting from the operational environments. Based on the monitored state, appropriate repair, rehabilitate, and/or strengthening of structures are decided to keep these structures operational and further to lengthen their lives.

This ability of SHM in identifying the location and severity of structural damages by considering any changes in characteristics of the structures such as their frequency, stiffness and mode shapes helps engineers to monitor the structures and help engineers to find an effective solution.

Cost of monitoring and repairing is much lower than cost of reconstruction of new structures, hence countries like Japan and USA have been putting a lot of effort in studying this technique.

CHAPTER 2
INTRODUCTION

Current damage detection methods are either visual inspection or localized experimental methods such as acoustic emission, ultrasonic methods, etc. All of these experimental techniques require that the vicinity of damage is already known and the portion of the structure being inspected is readily accessible. Related to these limitations, these methods can detect damage on or near the surface of the structure. In addition, the problem of current practice is also compounded by the shortage of experienced inspectors and the inevitable time delay caused by in-depth structural analysis. As a result, the need for additional global damage detection methods that can be applied to complex structures has arisen.

Due to inadequate inspection and insufficient quality of visual monitoring in structures such as tall buildings and long span bridges, major structural issues such as corrosion of reinforcing bar and steel components, and other internal defects have been overlooked. This problem can be solved by using SHM.

There have been various assessment techniques for a structure such as None – destructing testing (NDT) and NON destructive Evaluation , but these methods target one-time structural evaluation while SHM is implemented as a real time and ongoing structural assessment technique.

Some of them are reluctant to use SHM because they think that its very expensive but it has been proved that it can help in optimizing the life cycle cost of a structure by reducing the maintenance and continuous inspection, downtime cost etc

Monitoring significant factors such as load, deformation , strain, crank initiation in a key structural member can guarantee the extension of the structures life cycle by maintaining them in good health condition. Other significant factors such as its mass and stiffness are required to calculate the natural frequency of the structure. Natural frequency is significant , because it can prevent resonance. Resonance is the

phenomenon which occurs when frequency of the seismic waves matches the natural frequency of a building which can lead to the failure of the structure.

CHAPTER 3
TECHNIQUES OF SHM

1. *Impedance based SHM techniques*- Working principle is supplying electric power, sensing through PZT patches, hence through the help of signature obtained, we can detect, monitor and find the necessary solution.

2. *Data Fusion Techniques*- Same as impedance but the process of integrating data and knowledge representing the same real world object in consistent, accurate and useful representation.

3. *Vibration Control Technique*- Widely used technique from ancient time, it depends on vibration applied from the sensors, damping and signature getting from system.

4. *Acoustic emission(AE) Technique*- Continuous or periodic monitoring used in wireless and wired technology. In this echo of sound is measured.

5. *Smart sensors wireless technology*- They have been developed to complement the limitation of the conventional sensors such as electric resistance strain gauges, wired accelerometers and extensometers.

We have choose Impedance based SHM techniques and further studied about it in detail.

About CNT 's

CNT based PNC

This area has been progressing rapidly in recent years such as strain sensing, super capacitors , high end tennis rackets etc.PNC have better mechanical , electrical , peizo resistive and thermal properties compared to conventional conductive polymer composites.CNT's are becoming easier to produce but cannot be used in bulk form due to their poor translation of inherent properties of individual CNT's.

Polymer Nano Composite(PNC)

Polymer nanocomposites or nanofilled polymers[1] are polymer matrices containing organic or inorganic fillers with a homogeneous nanoscale distribution (normally from 10 to 100 nm in at least one dimension), which are prepared by physical blending or chemical polymerizing technologies. The fillers can be particles, layered materials, fibres or clusters embedded in a wide variety of natural or synthetic polymers. Their distinctive physical and chemical properties, enhance the performance of the composites

Carbon nanotubes (**CNTs**) are allotropes of carbon with a cylindrical nano-structure. These cylindrical carbon molecules that have unusual properties, which are valuable for nanotechnology, electronics, optics and other fields of materials science and technology. Owing to the material's exceptional strength and stiffness, nano-tubes have been constructed with length-to-diameter ratio of up to 132,000,000:1,significantly larger than for any other material.

In addition, owing to their extraordinary thermal conductivity, mechanical, and electrical properties, carbon nano-tubes find applications as additives to various structural materials.

Nanotubes are members of the fullerene structural family. Their name is derived from their long, hollow structure with the walls formed by one-atom-thick sheets of carbon, called graphene. These sheets are rolled at specific and discrete ("chiral") angles, and the combination of the rolling angle and radius decides the nanotube properties; for example, whether the individual nanotube shell is a metal or semiconductor. Nanotubes are categorized as single-walled nanotubes (SWNTs) and multi-walled nanotubes (MWNTs). Individual nanotubes naturally align themselves into "ropes" held together by van der Waals forces.

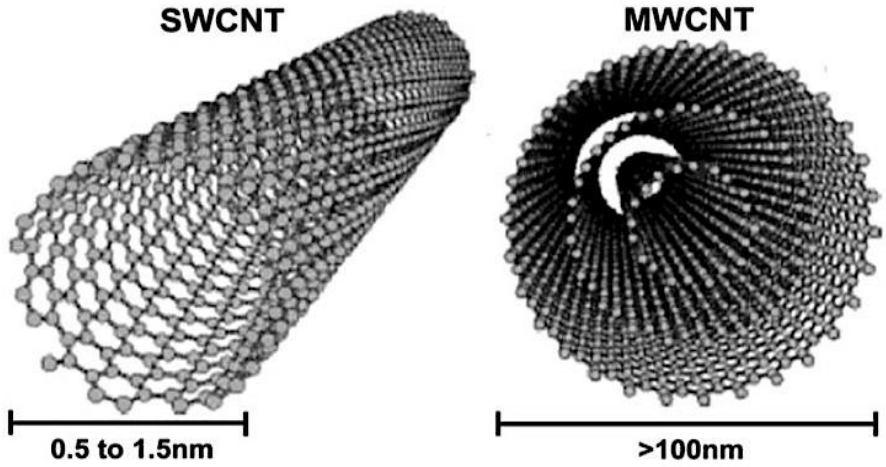
Single walled Carbon Nano Tubes

Single-wall carbon nanotubes (SWNTs) are a special class of carbon materials known as one-dimensional materials. They consist of sheets of graphene, rolled up to form hollow tubes with walls one atom thick. Due to its chemical structure and dimensional constraints, this material exhibits exceptional mechanical, electrical, thermal, and optical properties. As such, carbon nanotubes have become of great interest for both stand-alone studies and for use in composite materials.

Multi walled Carbon Nano Tubes

Multi walled carbon nanotubes consist of multiple rolled layers (concentric tubes)of graphene layers in a one dimensional format. The properties of Multi Walled Carbon Nanotubes are unique because they come in a complex array of forms and each

concentric nanotube can have a different structure, there are a variety of sequential arrangements. The simplest sequence is when concentric layers are identical but different in diameter. However, mixed variants are possible, consisting of two or more types of concentric Carbon Nanotubes (CNTs) arranged in different orders. These can have either regular layering or random layering.



Mechanical Properties

Table 1: Theoretical and experimental properties of CNTs (Xie et al., 2005)

Properties	SWCNTs	MWCNTs
Specific Gravity	0.8 g/cm^3	1.8 g/cm^3
Elastic Modulus	~1 TPa	~0.3 – 1 TPa
Strength	50 – 500GPa	10 – 60 GPa
Resistivity	5 – 50 μΩ cm	5 – 50 μΩ cm
Thermal Conductivity	3000 W m^{-1} K^{-1}	3000 W m^{-1} K^{-1}
Thermal Stability	>700 °C (in air); 2800°C (in vacuum)	>700 °C (in air); 2800°C (in vacuum)
Specific Surface Area	~400-900m^2/g	~200 – 400m^2/g

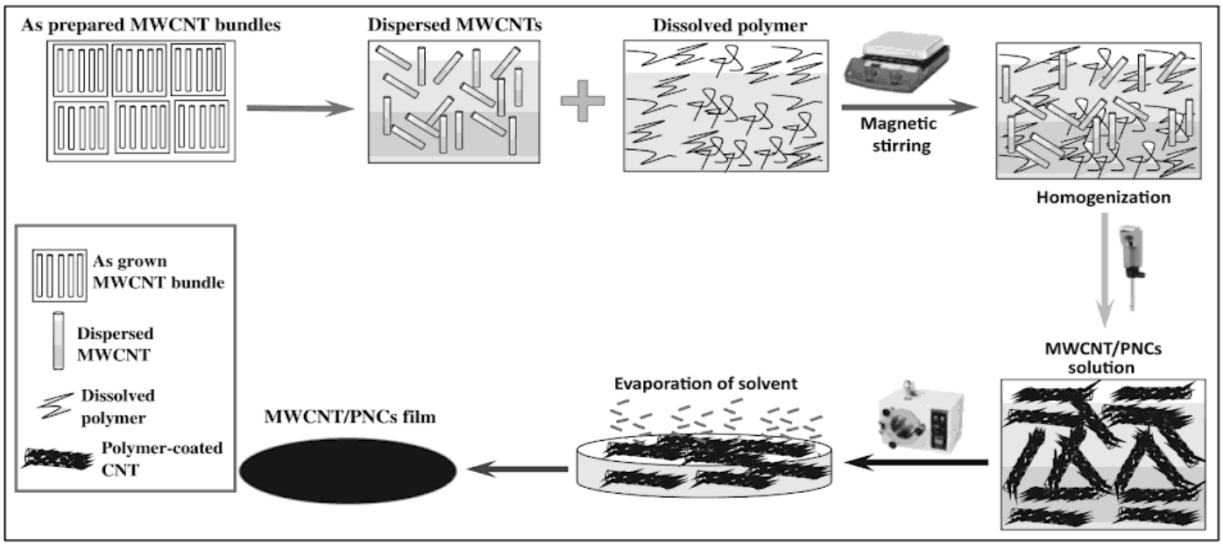
SOURCE-http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0104-66322010000200002

CHAPTER 4
FABRICATION TECHNIQUES

Traditional approaches

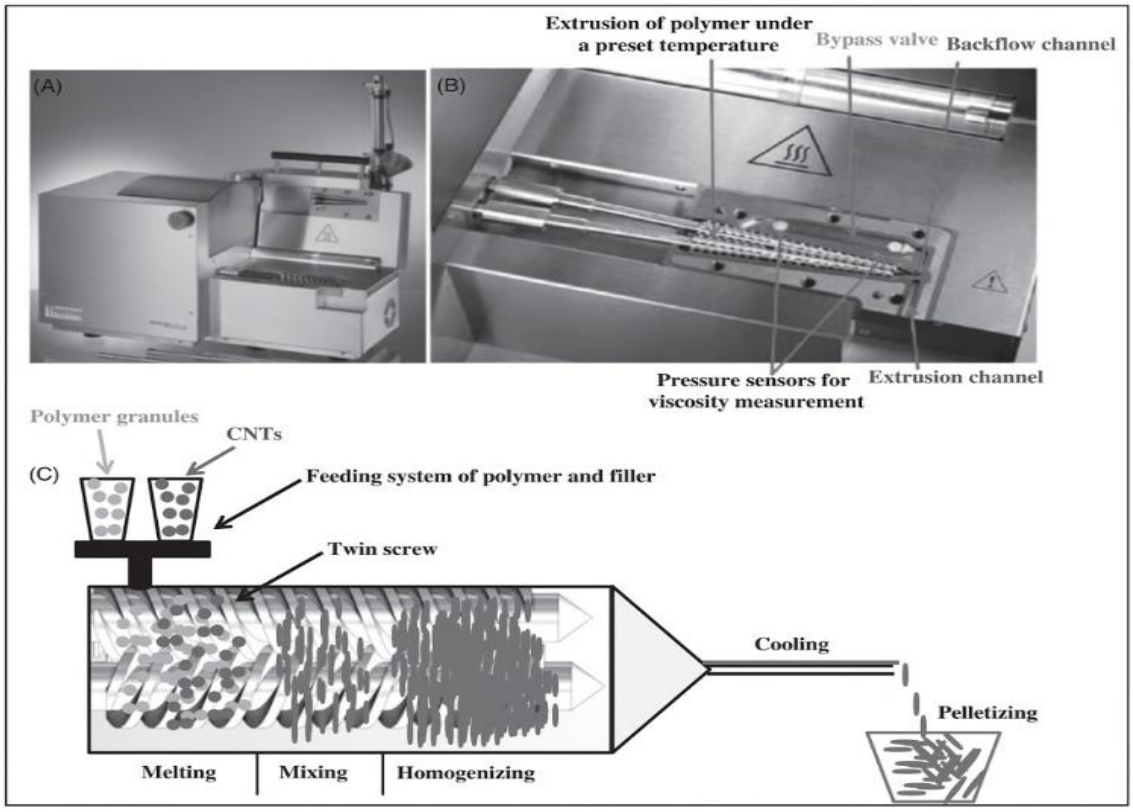
1.*Solution Mixing Technique*

It is one of the most useful methods for the fabrication of CNT/PNCs on a Laboratory scale. CNTs and polymer are mixed separately in a solvent. Dispersed CNTs and polymer are mixed together and a composite film is produced with or without vacuum-assisted solvent evaporation. Ultra-sonication, magnetic stirring and high-speed homogenization techniques are used to disperse and mix CNTs properly into the polymer matrix. The boiling point of the solvent used has impact on properties of PNCs. This method helps in debundling the CNTs and improves the quality of dispersion in polymer matrix. This technique cannot be used for insoluble polymers.



2. *Melt Blending Technique*

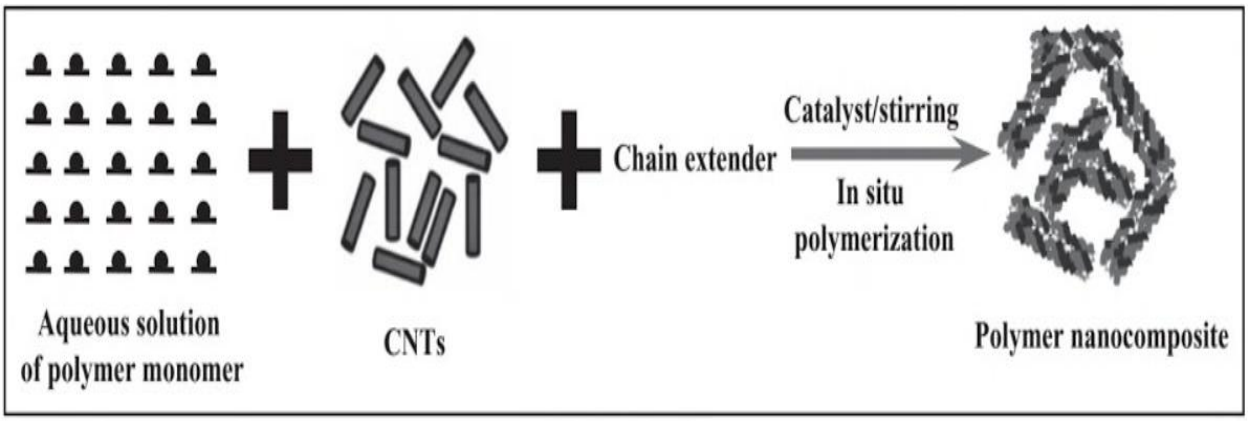
It is the most promising technique in fabrication of thermoplastic PNCs on an industrial scale due to its low cost. Melt processing involves blending of polymer matrix with CNTs by the application of shear forces at elevated temperatures, which contributes in partial de-agglomeration of CNT bundles and their dispersion into the matrix. High shear mixer and twin screw extruder are used for batch or continuous operation of melt blending. Polymer granules and CNTs are loaded into the extruder via separate hoppers and mixing happens at the melting zone due to shearing action and then reaches homogenization. The mixture becomes semisolid and cooled by air drying or by water bath and are granulated or composites of desired size and shape can be made using an injection molding machine. This technique is not good for materials that degrade with temperature. Shear force and temperature are needed to be properly optimized to achieve appropriate dispersion without compromising intrinsic properties of CNTs and polymer matrix.



3. *Insitu Polymerisation Technique*

It is very effective method to improve the dispersion and interaction of CNTs in polymer matrix.Dispersed CNTs are mixed with a monomer solution and then polymerization takes place in presence of an initiator. This method provides good dispersion and compatibility between polymer chains and CNTs. This method also

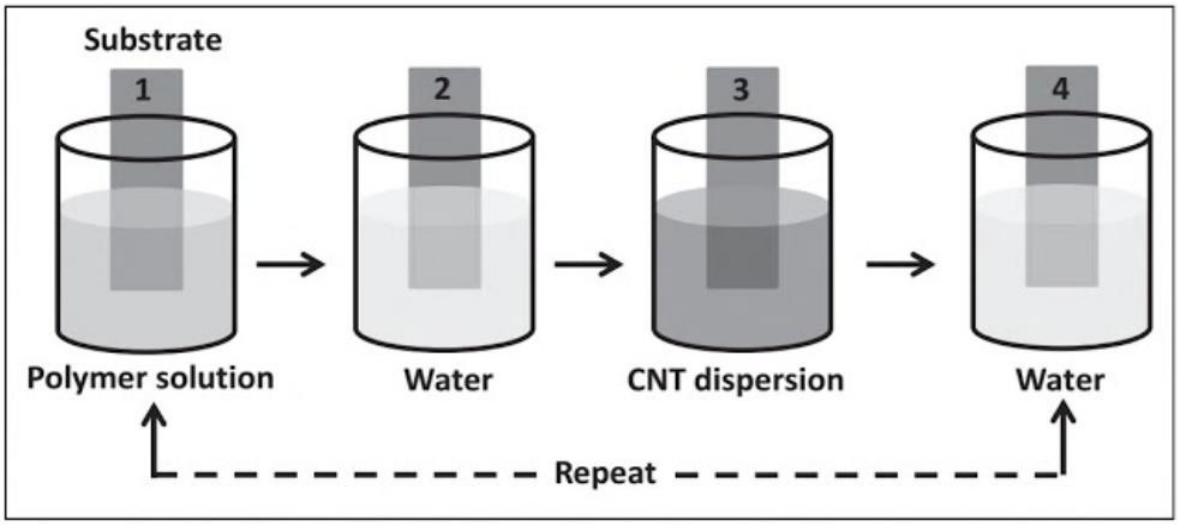
provides a stronger and more active interface between polymer and CNTs. It is less applicable as it requires a large amount of solvent for processing.



New Approaches

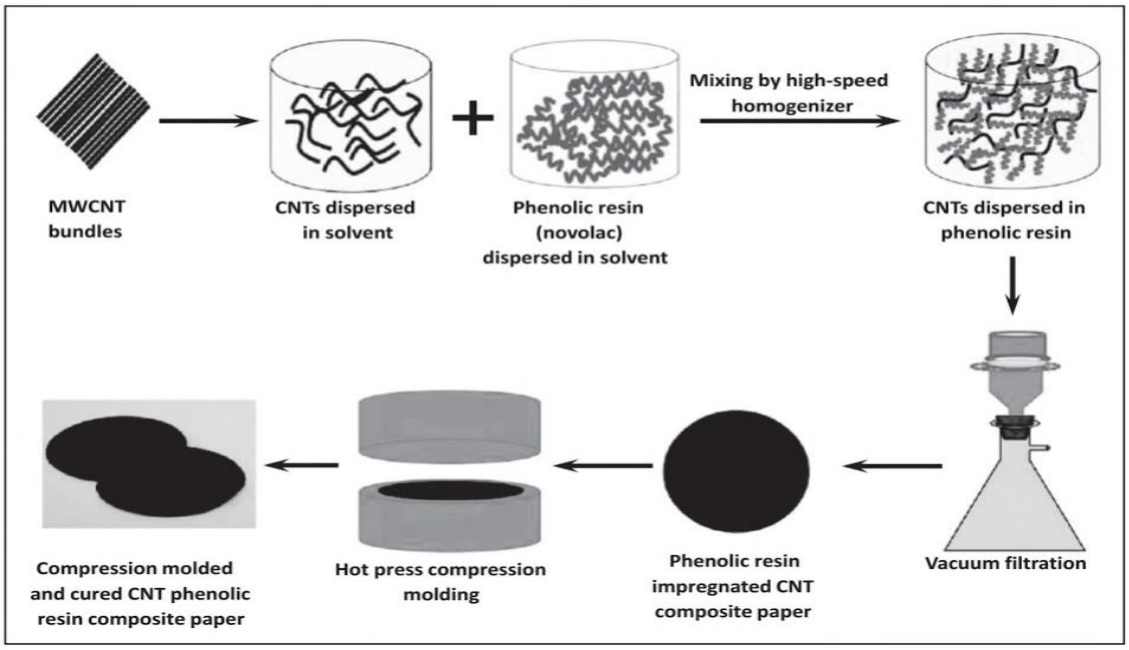
1.*Layer by Layer route*

Layered composite film is developed on the substrate by dipping the substrate alternately in a CNT-dispersed polyelectrolyte solution. First substrate in dipped in positively charged electrolytes and rinsed in water to remove loosely attached polyelectrolytes. To grow LBL further, the substrate is dipped in negatively charged polyelectrolyte solution, as a result, a double layer of polyelectrolyte is attached on the surface. This method has significant advantages as the thickness and CNT ratio can easily be controlled and high nanotube loading can be obtained.



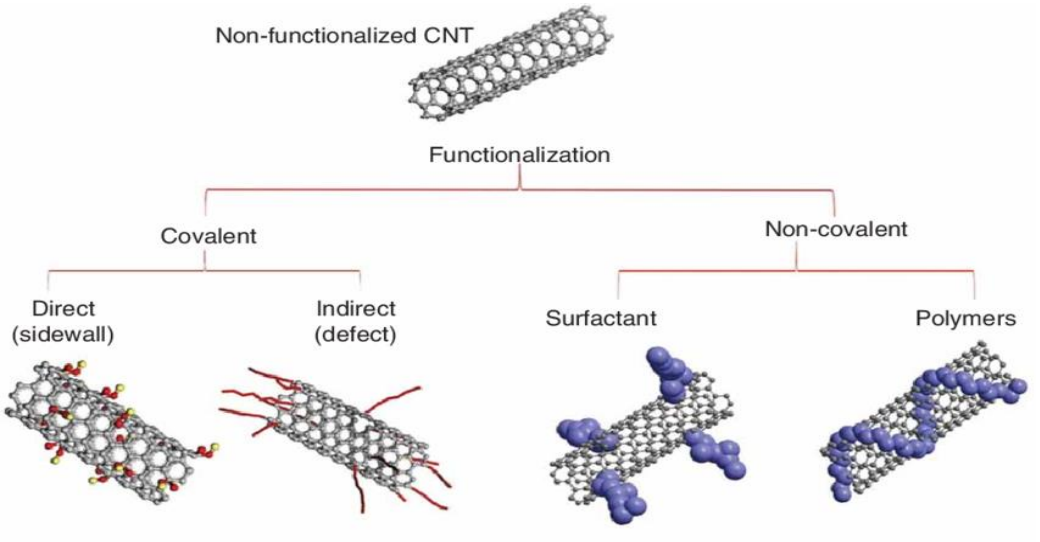
2. *Buck Paper Approach*

Bucky paper is a thin, porous sheet of CNTs usually formed by filtration of CNT dispersion. The bucky paper sheet can also be inserted between laminates to enhance the mechanical properties.



Chemical Modification of CNT

Two major approaches are covalent and non-covalent functionalization



Covalent functionalization-

It is done by addition reaction of chemical reagents to the sidewall of CNT. The Functional groups attached belong to carboxylic or amine group. This Leads to stable

dispersion of CNT.The most common method for surface functionalization is by oxidation with acid treatment. Acid modified CNTs improve interfacial bonding.

Non Covalent functionalization-

The main forces involved are van der Waals, pi-pi bonds and electrostatic bonds. The advantage is they don't alter the structure of CNT. Several approaches for this method are surfactant-assisted dispersion, polymer wrapping, plasma polymerization etc. Enhances interfacial bonding in the polymer matrix.

CHAPTER 4
Literature Review

Study on SWNT/PMMA and Buckypaper

Fabrication of SWNT was done in two ways, the SWNT obtained were dispersed in dimethyl form amide (DMF) solvent, 1.5mg ml−1 and was put in bath sonicator for 20h to achieve a well dispersed CNT in the mix, if the nanotube bundles are not separated into tiny bundles they can affect the mechanical and electrical properties. After the dispersion processing, the SWNT suspension solution was poured into P8 filter paper, or a Teflon casting mold, and dried in a vacuum oven at 60–70 ◦C for 12 h to slowly dry in a vacuum oven at 60–70 ◦C for 12 h to slowly evaporate the solvent to obtain the freestanding buckypaper film. This film composed of highly entangled SWNT bundles held together by van der Waals forces.

The SWNT based composite material was also fabricated keeping in mind that strain applied to the structure is transferred to the nanotubes in the sensor and the buckypaper sensor has some slippage among the nanotubes in bundles because there is only weak bonding due to the van der Waals interactions at the junction points of the nanotubes. This may hamper
strain transfer through the whole sensor and degrade strain measurements. In this study, polymethyl methacrylate (PMMA) was used as a polymer binding material because it is simple to handle and to mix with SWNTs in a solvent (DMF). PMMA was added to a suspension of SWNTs in DMF and mixed using shear force. After the dissolving and mixing process, the liquid was cast in a Teflon mold to form a sheet and it was initially cured in a vacuum oven at room temperature for 30 min to remove air. It was then fully cured in a low vacuum (16-inch Hg), at 120 ◦C for 12 h to evaporate the solvent. Finally, the SWNT/PMMA composite film was detached from the mold.

The properties of the sensor strongly depend on the material processing because it is a nanocomposite. Electrochemical impedance spectroscopy (EIS) testing was performed to characterize the electrical properties of the SWNT/PMMA sensor material and to help develop an electrical model of the material. EIS testing is done mostly to that analyze the materials relationship of their conduction and capacitance of the sensor. The EIS is usually measured by applying a small amplitude AC potential and a fixed DC potential to an electrochemical cell and measuring the current through the cell. The impedance was calculated, it was done for different frequency and to calculate their respective impedance. An equivalent electrical model was developed comprising of a resistor and capacitor in parallel. To verify the electrical modeling of the circuit, a Nyquist plot was simulated based on the estimated parameters. An electrical model of the nanocomposite is required in order to optimize its sensing characteristics in electrical circuits. It is also important to know how the sensor impedance parameters are related to the material process. The EIS can help us to understand how to improve dispersion of the nanotube in the polymer to reduce the resistance, and this will help to design a longer continuous strain sensor. It is expected that improved sensitivity and longer sensors can be obtained from the improved composite fabrication process.

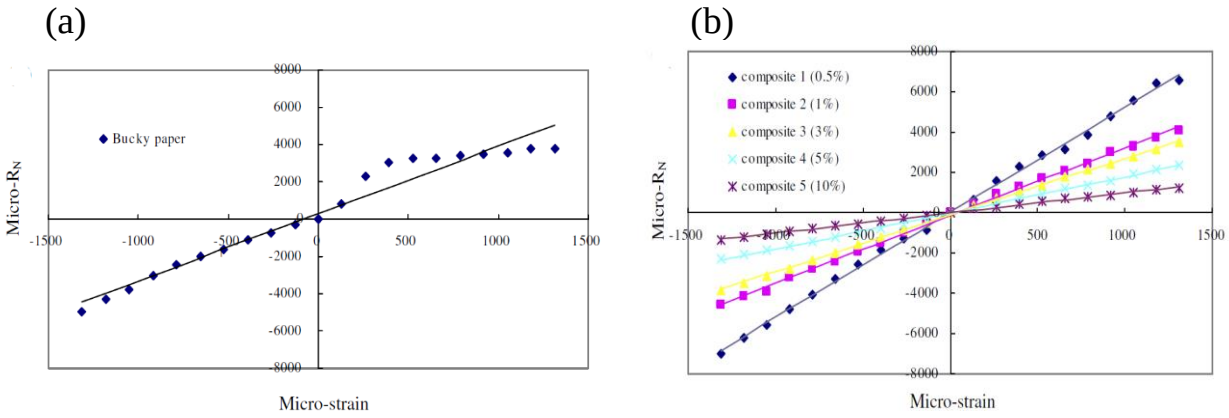
A strain response modelling was done on a dry structure A set of CNT strain sensors was attached to the surface of a fiberglass beam. A fiberglass cantilever beam was used
because it is a simple structure. One end of the beam was clamped. Each strain sensor was
tightly bonded using a vacuum bonding method to ensure that the superglue makes a stiff bond to transfer the strain across the sensor without any slippage. The sensors were connected to wires. The beam end displacements and change of resistance of the individual sensors on the beam were measured when the beam was deflected.

The change of resistance of each strain sensor was measured with respect to the displacement due to bending of the cantilever beam. The strain in the beam (ε) was derived from cantilever beam theory. Using beam theory, the stress beam was found out and the with elastic modulus present the strain was found out. The change in resistance of the strain sensors was measured with a multi-meter and the values were converted to a normalized change of resistance (RN)

$$R_N = (R\text{s} - R_O)/ R_O$$

where R_0 is the resistance without any displacement or strain and R_s is the measured sensor resistance when the beam is strained. It was reported that the electrical properties of SWNTs showed change over a wide temperature range and change due to pressure. Since they were developing a resistance strain sensor, it is assumed that

the resistance of the SWNT based sensor only changes due to strain, and the capacitance does not change in this study.



Strain modeling of: (a) a buckypaper sensor; (b) SWNT/PMMA composite sensors with different weight percentages of SWNT in the PMMA.

The strain response of buckypaper shows a higher sensitivity than other composite sensors in the linear bending range, but in tension it shows a saturated nonlinear behavior above the 500 microstrain range. This is probably due to the contact separation and slip of the SWNTs which are entangled with simple mechanical bonding in the buckypaper. Therefore, buckypaper may not be suitable for measuring strain in the whole elastic range. While the composite strain sensors showed less sensitivity(slope) than buckypaper, they showed quite a linear symmetric strain response in both compressive and tensile bending cases. Because the polymer bonding prevents sensor slippage, it effectively improves the strain transfer across the composite sensor and shows a linear strain response with load. It can be observed in the above plots. Composite 1 with 0.5% has high sensitivity and is linear and would be a very good choice for the application.

Study on MWCNT-low density polyethylene nano composites

A linear LDPE polymer is investigated because of its usefulness in civil industries. A conductive filler of Carbon Nano Tubes (CNT) is used and the level of electrical conductivity depends upon the concentration, geometry, orientation and distribution of the filler.

Multi-walled carbon nanotube (MWCNT) is an ideal filler for the fabrication of polymer nano composites, due to their excellent mechanical, thermal and electrical properties.

Fabrication:

LDPE nanocomposites with different wt% of MWCNTs (0.0, 0.1, 0.5, 1.0, 2.0, 3.0, 4.0 and 5.0) were fabricated via solution mixing, followed by a compression moulding technique.

In this method LDPE pellets were first dissolved in toluene using magnetic stirring and MWCNTs were dispersed separately in ethanol using a horn sonicator at an amplitude of 20% to obtain a stable suspension of CNT in ethanol.

The suspension of MWCNTs was mixed with a solution of LDPE by magnetic stirring and then transferred onto a flat petri dish and finally placed in an oven at 80 °C for 12 h to evaporate the solvent. The mixed powder of MWCNT-LDPE nanocomposites was compression moulded at 140 °C for 5 min using a hydraulic press and the resulting sheets of 1 mm thickness were cut to the desired size and shape according to the standards for mechanical, electrical, thermal and piezoresistivity tests. The same procedure was used to prepare all of the LDPE nanocomposites from 0.1 to 5.0 wt% loading of MWCNTs.

Characteristics of MWCNTs:

Surface morphology and structure characterizations were carried out using SEM, TEM and Raman spectroscopic techniques.

The Raman spectroscopic studies of MWCNTs, neat LDPE and MWCNT-LDPE nanocomposites gives us some knowledge of the microstructure. It observes vibrational, rotational, and other low-frequency modes in the system.

Mixing of different wt% of MWCNTs in LDPE matrix, the Raman bands of neat LDPE weaken up to 0.5 wt% of MWCNT loading and finally disappear at higher loadings. The presence of D-band and G-band indicate the effect of MWCNT dispersion in the LDPE matrix and the LDPE chains penetrate between the MWCNTs during hot pressing. This systematic increment in the peak intensities of D- and G-band depend upon the wt% of MWCNTs.

Where the G band is the first-order Raman band of all sp2 hybridized carbon materials. The D band is a defect activated band in sp2 hybridized carbon materials.

The overall improvements in UTS, yield strength and Young’s modulus were found to be 59.6%, 48.5% and 129.3%, respectively for 5.0 wt% loading of MWCNTs in LDPE matrix.

A significant increase in electrical conductivity from 10−13 Scm−1 for the neat LDPE to 2.38 × 10−2 Scm−1 for 5.0 wt% loaded MWCNT-LDPE nanocomposites was achieved with a low percolation threshold of 1.0 wt%. The thermal properties highlighted the enhancement in thermal stability as well as crystallinity of these nanocomposites.

These nanocomposites also possessed good self-sensing properties with good sensitivity (gauge factor) in the range of 4.88–52.82 for PECNT1to PECNT5 in the linear elastic regime. Therefore, these nanocomposites can be useful for strain sensing applications in linear elastic regime. In inelastic regimes, these composites provide good sensitivity up to 15% of strain. Therefore, they can also be useful for damage sensing and SHM (at higher strain levels).

Study on Thermosetting Polyurethane Multiwalled Carbon Nanotube Composites

The vast majority of literature has reported on thermoplastic/CNT composite materials, but to a much lesser extent on thermoset-CNT composites, somewhat surprising as thermosets account for 25% of the global market of all natural and synthetic polymeric materials. The majority of thermoset-CNT studies have focused on epoxy- and thermosetting polyimide CNT composites.

Fabrication

The thermoset PU used in the study was a two part rigid polyurethane system consisting of an isophorone diisocyanate and a polyetherpolyol.

The polyurethane precursors were degassed for at least 8 h before processing in a vacuum oven at -1.0 mbar vacuum pressure. The MWCNTs were dried for at least 8 h at 808C. Loadings of 0.1 and 1.0 wt %. MWCNTs were added directly to the isophorone diisocyanate. Using a three port round bottom reaction flask, the MWCNTs were admixed and sheared using a high shear mechanical mixer set at a rotor speed of 500 rpm for 90 min. A constant vacuum was applied to degas and to keep the mixture as dry as possible during processing, as both precursors are extremely hygroscopic. The second precursor (polyetherpolyol) was slowly injected into the reaction flask through a sealed opening and stirred slowly for a further 10 min. The mixture was then allowed to rest under vacuum for a short time to minimize foam and bubble formation before removal. Samples for mechanical testing were produced by injecting the liquid mix into predried PTFE molds, machined to standard

test dimensions according to tensile test requirements detailed in BS EN ISO 527-2:1996.

Results

The tensile properties, Young's modulus, ultimate tensile strength (U.T.S.) and percentage elongation at break of the pure PU resin and PU/MWCNT composites were recorded. The Young's modulus of PU resin increased by 97 and 561% from 6.4 to 12.6 to 42.34 MPa on the addition of 0.1 wt % and 1 wt % MWCNTs respectively. Concomitantly, the U.T.S. of the PU/MWCNT composites increased by about 397% when either 0.1 or 1 wt % MWCNTs were mixed with the neat PU resin. Furthermore, the percentage elongation at break (relative measure of toughness) of the resin increased from 83 to 302% on the addition of just 0.1 wt % nanotubes, then decreased slightly when 1.0 wt % MWCNTs was added to 272%, compared to the virgin thermoset material.

Work Done

Fabrication of the Mould

We used telfon as the material for fabrication of the mould because of its useful properties like high flexural strength, high melting point at 327°c, almost totally chemically inert, highly insoluble in most solvents or chemicals, and thermally stable enough to be used between -200 degrees C and +260 degrees C without degrading. A square block of 100×100×5 mm is used with 80×80×2 dimensions pocket milling on both of the square disks with one being male and other female part.

Teflon Mould

Fabrication of the Sensor

At first only pure mould grade ldpe is used to fabricate a sensor. At first, we used water as a medium to transfer heat. Toluene is used to dissolve the ldpe with constant heat and magnetic stirring. 5 grams of ldpe is dissolved in 50ml of toluene after 4 hours. The dissolved solution is left out for an entire night to evaporate toluene at normal conditions. The left out ldpe is heated at around 120°c and transferred to the ptfe mould. It was compacted using weights of 60 kgs. The compressed ldpe film is then taken out for analysis.

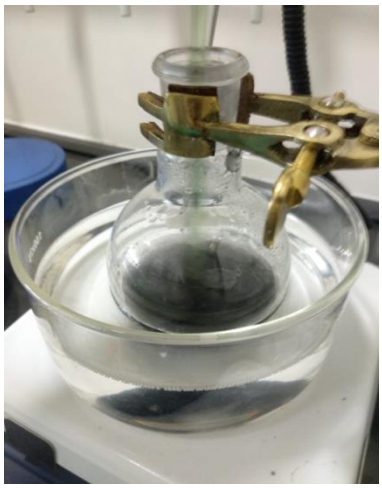
After discovering that the mould grade ldpe is not giving required results, we changed to linear low-density polyethylene. The same above process is used for fabricating pure lldpe sensor. After satisfied with properties of lldpe sensor we continued fabrication with this time using CNTs in the polymer. 5 grams of lldpe is first mixed with toluene solution and 1% at 0.45 grams of CNTs is also mixed with toluene and continuously stirred for an hour to disperse CNTs properly into the solution. Both the lldpe and CNTs solutions are mixed and heated at 85-90°c, magnetically stirred for two hours. Once the lldpe is dissolved in the solution it is left over for an entire night. Similarly, the lldpe and CNT polymer is heated and compressed. The polymer film is then taken out for analysis.

LDPE Mould Grade

LLDPE Film Grade

Process of Solution Mix Fabrication

1. **For 1% CNT , PNC was made**



2. **Sample was left to dry overnight**

3. **Sample was compressed using dead load**

4. **End result after compression**

Challenges faced

We had been told that the lab will provide the necessary chemicals required for the method of fabrication we had chosen. But when we were about to start the process of fabrication, there was a shortage of chemicals required and necessary equipment. Due to some other circumstances, we had to decide the number of chemicals, equipment required and procure it from third-party vendors. Because of this, there was a lot of delays. This wouldn't have happened if the lab had provided us with the necessary materials and equipment.

We were supposed to fabricate LDPE/CNT sensor in which the polymer matrix is LDPE. We procured LDPE from the market. With the necessary material procured a pure LDPE matrix was fabricated to test its physical properties. The resulted LDPE matrix was very brittle. We realized that with this LDPE the fabrication process was not possible, hence we decided to use another polymer matrix which was polyurethane. While doing further research, we came to know that there were mainly two grades of LDPE available. The one we used was LDPE mould grade, but we came to know that, by using LLDPE film grade we would get better results. It took us a lot of time to procure LLDPE film mould which resulted in a lot of delays.

We needed a hydraulic press for compression of film. The equipment was available in IIT Hyderabad and RCI but due to other reasons that were not possible to use their resources. We made our own mould made of Teflon with the help of mechanical lab using CNC milling machine(Pocket Milling).

While we were in the final stages of fabrication, there was a spillage of mercury. Due to this, in order to neutralize the mercury with sulphur, the lab was closed for a

period of one month. We finished the fabrication after the opening of the lab. Due to the nonfunctional of the equipment in the material testing lab, we couldn't do the basic tensile test.

What can be done in future

Fabrication of multiple polymer samples and conduct basic tests.

To find correlation between the strain and conductance.

Also fabricate polyurethane PNC

Collect data from the correlation between the strain and conductance

Develop algorithms to precisely correlate the sample data with the data we collect to detect any cracks.

CONCLUSION

Initially we have studied about various fabrication techniques of CNT based PNC. Information regarding various tests conducted on CNT's were also studied and understood. We ordered the necessary material (Multi walled carbon nano tubes) and procured it from the vendor. Further studies regarding the method of fabrication was done, after various discussions with our mentors, the fabrication method was decided. After fabrication of different grades of pure ldpe, we came up with an optimised way of fabrication and incorporated CNTs into the ldpe. In future, the correlation between strain and conductance can be taken and algorithms developed to use the data to help in structural health monitoring.

REFERENCES

"A carbon nanotube strain sensor for structural health monitoring" by Inpil Kang1, Mark J Schulz1,3, JayHKim1, Vesselin Shanov2 and Donglu Shi2

"Self-sensing performance of MWCNT-low density polyethylene nanocomposites" by Tejendra K Gupta, S Kumar, Amal Z Khan, Kartik M Varadarajan and Wesley J Cantwell

"Fabrication of Carbon Nanotube/Polymer Nanocomposites" by Tejendra K. Gupta and Shanmugam Kumar

"Thermosetting Polyurethane Multiwalled Carbon Nanotube Composites" by Caroline McClory, Tony McNally, Gerard P. Brennan, James Erskine

"Effect of Processing Technique on LDPE Thin Films and sheets" by Irene S. Fahim, Wael Mamdouh, H. G. Salem

"Fabrication and Application of Polymer Composites Comprising Carbon Nanotubes" by Kausala Mylvaganam and Liangchi C. Zhang

"Structural Health Monitoring, History, Applications and Future". A Review Book by Mohamed Abdel-Basset Abdo

"Structural Health Monitoring of buildings and infrastructure" by Mojtaba Valinejadshoubi, Ashutosh Bagchi , Osama Mosheli