"Study of Health Monitoring Using Carbon Nanotube"

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in

Structural Engineering

Under the Supervision of

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CERTIFICATE

This is to certify that the work which is being presented in the project title **" Study of Health Monitoring Using Carbon Nano tube"** in partial fulfillment of the requirements for the award of the degree of Master's of technology and submitted in Civil Engineering Department, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out by ABHISHEK THAKUR during a period from July 2015 to May,2016 under the supervision of **Mr. Abhilash Shukla,** Assistant Professor, Civil Engineering Department, Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best of my knowledge.

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Place: JUIT ,(H.P) **Abhishek Thakur(142660)**

Date:

ABSTRACT

The objective of this research was to examine the piezoresistivity of CNT/cement composite and also to measure the stresses in three different stressed zone in beam i.e Uniaxial Compression zone, Biaxial Compression and shear zone, Uniaxial tension zone with the help of CNT/cement composite. Because of CNTs having Properties like strength and high aspect ratios, CNTs have been excellent reinforcing material for increasing the mechanical properties of composites.

The carbon nanotubes were obtained from United Nanotech Innovations Pvt Ltd. The piezoresitive property of CNT enables the CNT/cement composite to determine the stress/strain inside the structures such as pavements, bridge etc. Recent research work shows that the piezoresistivity or resistance of the CNT/cement composite changed proportionally to the compressive loadings. The piezoresistive responses of the composite at different concentration level of CNTs and at different water content were studied. Lab experiments were performed to analyse the CNT/cement composites. Controlled repeated loads were applied on the sensors. These composites were used to determine the stresses in beam in different stressed zones and results were compared with theoretical values. Also the deflection at the center of beam measured by Dial gauge.

Place: JUIT,(H.P) **Abhishek Thakur(142660)**
Date:

ABBREVIATIONS

Abbreviations	Description
CNT	Carbon Nano Tube
MWNT	Multiwall Nano Tube
DWNT	Double Wall Nano Tube
SWNT	Single Wall Nano Tube
SHM	Structural Health Monitoring
ASD	Active Sensing Diagnostic
PSD	Passive sensing Diagnostic
Hz	Hertz
LA	Laser Ablation
CVD	Chemical Vapour Deposition
Mpa	Mega Pascal

NOTATIONS

Symbols	Description
f_ck	Characteristic Strength
f_y	yield Stress
	Hinge
R	Resistance
L	Clear span of Beam
b	Width
d	Depth
	Micro
^Mu	Ultimate Moment
	Deflection
E	Young Modulus
V	Shear Force
	Shear Stress
^Ast	Area of steel
$^Mu;Lim$	Limiting Moment
^xu	Depth of Neutral Axis

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CHAPTER 1

INTRODUCTION

1.1 Need and Scope

Civil structures such as concrete pavements, infrastructures are liable to degradation phenomena due to different loading, material aging and environmental conditions. The capability to determine such damages in civil structures as early as possible is essential for the well-being of public. While many methods have been performed to measure the serviceability and state of the structures, there is still no efficient and economical method to regularly examine the structural health. Now a days, Structural Health Monitoring (SHM) takes dominance of the recent researches in nanotechnology and analyzing or sensing in order to examine the behaviour of a structure, assess its capability and analyze damage at an initial stage Because mostly previous methods developed to date for concrete SHM use such as piezoelectric ceramic sensors, optic sensors, strain gauges, and embedded sensors that are embedded in critical structural positions. But, these sensors are for point monitoring only and have the limitations of high cost, low survival rate, poor durability, expensive equipments, low sensitivity, expensive equipments and unfavorable compatibility with concrete structures.

The current aim is based on the fabrication of structural neural systems and wide spread sensor networks ,so that the structure also work as same as human neutral system, for integrated health management.

Miniaturizations and inter section are two essential need for successful application of structural neural systems. Carbon nanotube (CNT) based composites are very encouraging in this situation, since they make possible the development smart structural materials, embedded sensors, providing both structural capability and examine the response to applied stress/strain.
in structures, cracks and other parameters. This research work will focus on nanotechnology based CNT/cement composite for examine the structural health.

1.2 Nanotechnology

Nanotechnology is the technology which controll the size of matter at atomic ,moleculaar and nano scale i.e 10^9.Which helpful in design characterisation and dimesions of matter at nano scale.With the advancement of this technology products getting smaller stronger and more durable.Following picture describes the application of nano technology in various sectors.

Figure 1.1: Application of nanotechnology

1.3 Carbon Nano Tubes (CNTs)

1.3.1 Introduction

Carbon nanotubes have always existed in nature; however they were rst discovered in1952 by Russian scientists L. V. Radushkevich and V. M. Lukyanovich.Still, Carbon Nano Tubes (CNTs) were not scienti callyrecognized and used until the last two decades. In 1991, published the article that systematically describes the information of helical micro tubes made of pure carbon atoms joined together by carbon-(C-C) bonds. There are many known forms for carbon structures in nature, like diamond, graphite, graphene, and Carbon Nano Tubes (CNTs) can be imagined as a rolled graphene sheet whose structure is made of one layer of carbon atoms bonded by carbon sp2 bonds in a hexagonalpattern. Graphene sheets

Were investigated for the rest time in 2004 by the 2010 Nobel Prize winners in physics, Andre Geim and Konstantin Novoselov, Russian scientists from the University of Manchester. Car-bon Nano Tubes (CNTs) can be assumed to be a graphene sheet rolled in a cylindrical(tube) shape and closed at both ends by half fullerenes or another carbon structure.

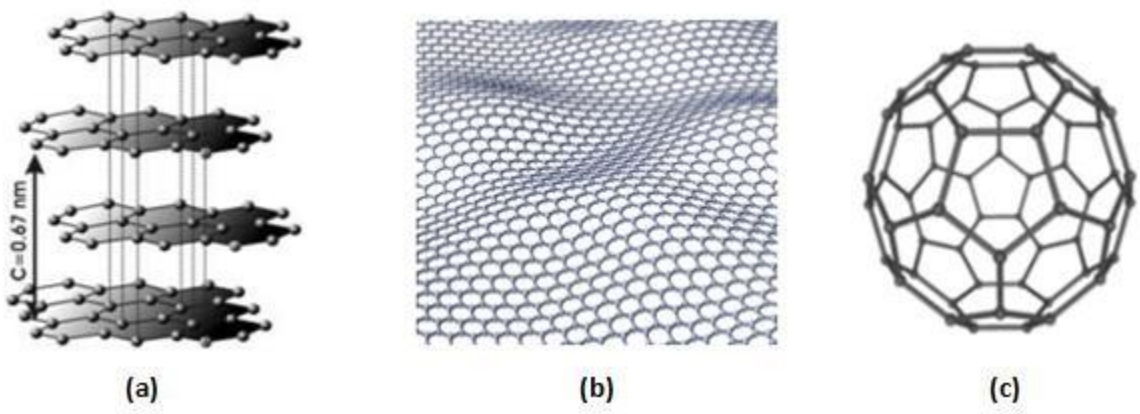


Figure 1.2: Comparison Between an (a) Graphite structure (b) Graphene Sheet and (c) Fullerene (bulkyball) structures

1.3.2 Types

SWNTs: - SWNTs are the tubes of graphite which are manufactured by folding a one atom layer of Graphite into a cylinder and capped at its ends. (Fig 1.3 (a)).

MWNTs: - Multiwall nanotubes consist of multiple layer of Graphene. These possess high strength and more sensitivity to others (Fig 1.3(b))

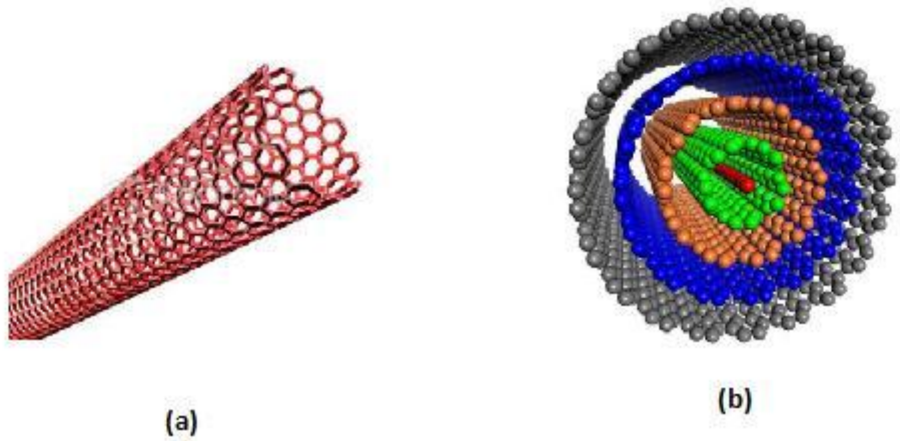


Figure 1.3: Schematic of an (a) (SWNT) and (b) (MWNT)

1.3.3 Manufacturing

There are three main approaches to manufacturing CNTs: chemical vapor deposition (CVD), electric arc-discharge, and laser ablation (LA).

The Chemical vapor deposition (CVD) method is the most commonly used method; it is relatively less complicated and is economical for large production of Carbon Nanotubes.It also manufactires Carbon nanotubes (CNTs) with high purity.The metal catalyst (Fe , Co) is used to initiate Carbon nanotubes (CNT) formation by mixing hydrocarbon gases like ethylene methane or acetylene in a reactor with a process gas (ammonia, nitrogen, hydrogen) using atmospheric pressure and high temperature. The type and size of the metal catalyst, along with the pressure and temperature in the reactor, will determine the produced CNTs properties, including dimensions and purity.

CNTs can be manufactured by giving an electric arc between two carbon electrodes,surrounded by an inert gas like helium.Carbon needles that are used 4 to 30nm in diameter and 1 mm in length. The high temperature from the arc (up to 3000 deg C) will sublimate the carbon atoms and form the conceptulised structure of the CNTs. This process will not manufacture a high purity of CNTs (around 30% pure CNTs by weight).

The Laser ablation process (LAP) manufactures a high purity of CNTs (around 30% pure CNTs by Weight). This process utilize a pulsed laser beam strikes to a graphite at a very high temperature under surround of inert gas. The vaporized gas is then cooled and condensed to form the Carbon nanotubes (CNTs). The dimensions of the carbon nanotubes will depend on the temp. of the reactor. This is most costly method; but, it gives homogenous and pure Carbon nanotubes (CNTs).

1.3.4 Properties

1.3.4.1 Mechanical

Carbon nanotubes are stronger material than steel and kelvar in terms of elongation at break and young modulus. Their strength comes from the covalent bonds between carbon atoms. Carbon nano tubes are stronger in compression because of high aspect ratio and hollow structures. It undergoes buckling when subjected to bending and torsional stresses.These are stronger than steel but much lighter.

1.3.4.2 Electrical properties

CNTs are one dimensional conductor because electron propagate along the tube axis only. Its current denisty is 1000 times more than mettalic copper.Conductive property of carbon nanotube which enables us to used in cement composite to determine demage criterias of the structure.

1.3.4.3 Thermal properties

Carbon nanotube (CNTs) have a thermal conductivity of about 3000 watts per meter per Kelvin, Which is more than diamond (900-2300 watts per meter per Kelvin) and Copper (400 watts per meter per Kelvin).Its conductivity is large along its axis because vibration of Carbon (C) atom propagate easily down the tube.

1.3.4.4 Comparison of properties to other materials

Table 1.1: Comparison of mechanical properties

Fiber material	Speciffc density	Young Modulus E (Tpa)	Strength (Tpa)	Elongation at break
Carbon Nano Tube	1.3-2	1	10-60	10
HS Steel	7-8	0.2	4.1	10
Carbon Fiber	2-2.2	0.4-0.96	2.2-3.3	0.27-0.6
Glass	2.5	0.07	2.4	4.8
Kevlar49	1.4	0.13	3.6-4.1	2.8

Table 1.2: Comparison of Transport properties

Material	Thermal Conductivity (W/m.k)	Electrical Conductivity
Carbon Nano Tubes	3000	10^6-10^7
Copper	400	$2x10^6$
Carbon Fiber	1000	$6x10^6$

1.3.5 Defects

1.3.5.1 Toxicity

Carbon nanotubes (CNTs) are capable of producing broses, in ammation and biochemical changes in lungs.Even Single wall nanotubes are more toxic than quarts, that is serious health problem.

1.3.5.2 Crystallographic defect

These defect affects the Thermal and electrical properties of the CNTs .Which can create deficiency in atom conjurations. Which reduces the strength of the material.

1.3.6 Advantages

light in weight and small size .

Sources are many to manufacture CNTs.But it requires less material. No

effect of temperature on CNTs.

It increases the electrical conductivity of the material.

1.3.7 Disadvantages

Still no exact idea to fabricate CNT in material. .Its

Complicated to work with so small size.

Now a days, the Synthesis of CNTS are relatively costly.

Costly to work with CNTs.

1.4 CNT based cement composites

The cement is mixed with carbon nano tubes, which create an uniform internal electrical conductive network and the piezoresistivity properties of the carbon nano tubes will enable us to nd the stress / strain inside the concrete.It can also act as the concrete reinforcement element that could increase the tensile strength and durability of the structure. CNT / cement composite and concrete are uniform cement-based material.

1.5 Piezoresistivity

Piezoresistivity made from two world Piezo + resistive. Piezo means " to squeeze ". Piezo-electric materials develop charge or change resistance when stressed.

1.5.1 Materials

It has a ability of certain materials to generate an electric charge when stress or force is applied.These can not be isotropic. If there was symmetry in the material there would not yield electric polarization. if we apply stress on certain crystals, then their molecules produces a charge after the realignment. A charge can be read as a voltage. A piezo electric crystal is like a capacitor that is pressure sensitive. CNT based cement composite is also the good example of piezoelectric material.

1.6 Objective

- This research was focused on a nanotechnology based CNT / cement composite for structural health monitoring.
- Study the behaviour of CNT / cement composite at different concentration level of water and CNT.
- Study the behaviour of CNT / cement composite under repeated loading.
- To check the sensitivity of sensor in held we compare the deflection of beam measure from the CNT/cement composite with the dial gauge readings.
- Comparing of stresses inside the beam measure from the embedded CNT based cement composite sensor at three different stress zones i.e. compression, compression and shear and tension. With theoretical values.

CHAPTER 2

LITERATURE REVIEW

2.1 Current methods of Structural Health Monitoring:-

Structural Health Monitoring of concrete has been a major research topic for years .There are many methods developed but These methods, while effective, are often time consuming, labor intensive, and impractical for in-service conditions.

There are two categories of SHMs: Passive Sensor Diagnostic/monitoring (PDS) and Active Sensing Diagnostic/Monitoring (ADS) . PDS uses passive senor signals to examine changes in condition of structures. ADS measurements can identify damage by examining the variation in parameter before and after the damages are induced. Of the above mentioned techniques for SHM of concrete:-

Many fall into the PDS method: coin tapping, x-ray, c-scan, and other methods are types of PDS monitoring and are conducted on site to determine extent of damage experienced during the service life of structure. PDS techniques can be used on existing structures and dont need to be incorporated during construction and design.

2.1.1 Coin Tapping

Coin tapping is a method of SHM of concrete structures through the use of phonic sound response. The method can be used to detect corrosion of reinforcement, poor quality con-crete.Measuring elaminations in structure components by sounding, covers the evaluation of affected concrete using sounding techniques.

Phonic testing of concrete has many applications in SHM on structures. While these results are quick, the results are highly depended on the operator. These method cannot be con-ducted in inaccessible areas and so require for an inspector being present in dangerous areas. There are many methods to conduct phonic testing of concrete deficiencies.

These tests coducted by tapping rigid bodies like hammer or coin on structure components. The difference between the sounds created during the taping is what allows for the determination of damage. When concrete creates a clear ringing sound upon impact, the test indicates that there is little or no problem with damage. Concrete that has issues with strength or debonding will have a dull or hallow sound when struck with the object. The difference in sound is due to a variation in the stiffness of the concrete.

2.1.2 Ultrasonic testing

Ultrasonic (sound having a frequency above 20,000 hz) method is another effective SHM method for concrete testing. Testing of materials using ultrasonic techniques uses the vibrations of the material that contains a given medium.

Ultrasonic method can utilized on a variety of materials including, but not limited to:Rock, liquids, metals, concrete, and various nonmetals. It is NDT for examining demages in concrete structures. It include deterioration due to attack of chemicals, cracking and due to freeze-thaw cycling.

This method is based on noticing the time of travel of wave through a medium. Ultrasonic method requires equipment to emit stress waves through the concrete and uses a separate device to measure the time it takes for the waves to travel through it. Time of travel of wave held us to and acoustic velocity of material from that we can judge the demage in structure.

Ultrasonic monitoring of construction materials delivers reliable readings of the instrument conditions of buildings. This method, however, is time consuming and impractical for global inspection. It is also not cost effective due to the high cost of using trained professionals to operate the equipment and to ensure the integrity of the readings.Elimination of the need for inspectors to reach inaccessible or dangerous areas is not accomplished in this test method.

2.1.2 Electric current induction or Eddy current method

Also known as the eddy current method.In this method, the material being explored needs tube electrically conductive, but not magnetically permeable.

Figure 2.1: A portable ultrasonic testing device

This method is not effectives as a direct monitoring technique of SHM. Concrete is a non magnetic material and the use of magnetic held to determine problem areas has not proved to be a reliable or stable technique. This technique, however, is effective or monitoring embedded steel or prestressing tendons.

2.1.4 Radiography

The most common form of radiation used are X-rays, however, Gamma rays are also used. The two forms of radiation used differ by the wave lengths. These are considerably shorter than that of visible light about 1/10,000 and 1/1,000,000 the length of visible on an image produced on radio sensitive screen with the help of radiation..

Testing using radiography is a great way to get an accurate portrayal of the damage that has occurred to a structure. Radiography is only used in areas that all surfaces of the structural element are exposed because of the need to have the wave emitter on one end and the lm on the receiving end. For this reason columns and wall elements are great candidates for this test method, however, the foundation and occur labs cant be tested. This test uses an expensive instrumentation, requires the use of a trained professional on site to handle the equipment and make judgments, and also is limited by accessibility. Due to the radiation that is emitted during the testing of construction materials, safety to the inspector and the public is a major concern, making this test impractical in many situations.

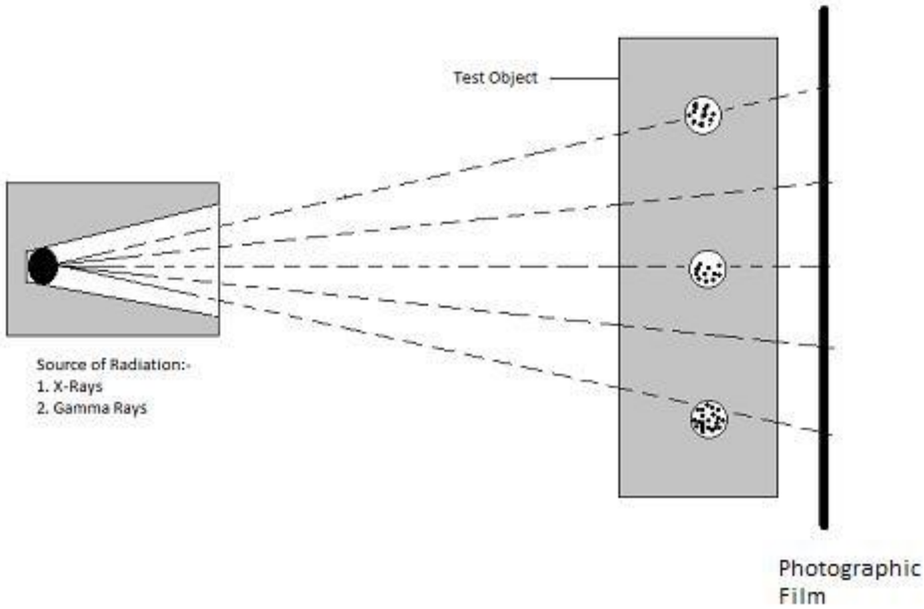


Figure 2.2: Schematic of Radiography

2.2 Sensors

To increase the safety of public with decreasing maintenance cost ,Structural Health Monitoring has attracted a maximum amount of attraction and has resulted in many journals, research paper , conferences and books about new and existing sensors. Every new type of sensor aims to to face many technical challenges that are occurred in transition of structural health monitoring from research laboratory to held. While this section of literature review focus on general type of sensors that are used as part of SHM: Stress ,strain, displacement, environment ,acceleration and environmental parameters.

2.2.1 Strain Gauges

A Strain gage is a device whose resistance varies with load; It changes pressure , weight etc., into a resistance which can then be evaluate .Following are the types of strain gages:-

1. **Piezoresistivity**:- These types of strain gages widely used in civil structures and these are embedded to structures so that deformation in structure causes the sensor to elongate or contract as well.

2. **Vibrating Wire:-** These are commonly used in large civil structures such as bridges.these are based on principle that if the wire is pinnes at both ends under tension than natural frequence of wire is measured of mode strain across the length to be measured from natural frequency.

3. **Optical ber** - optical bers which are bundlle of thin bers of glass and silica used ber properties to create optoelectric signals to demage or other parameter of structure.these are very fragile and expensive.

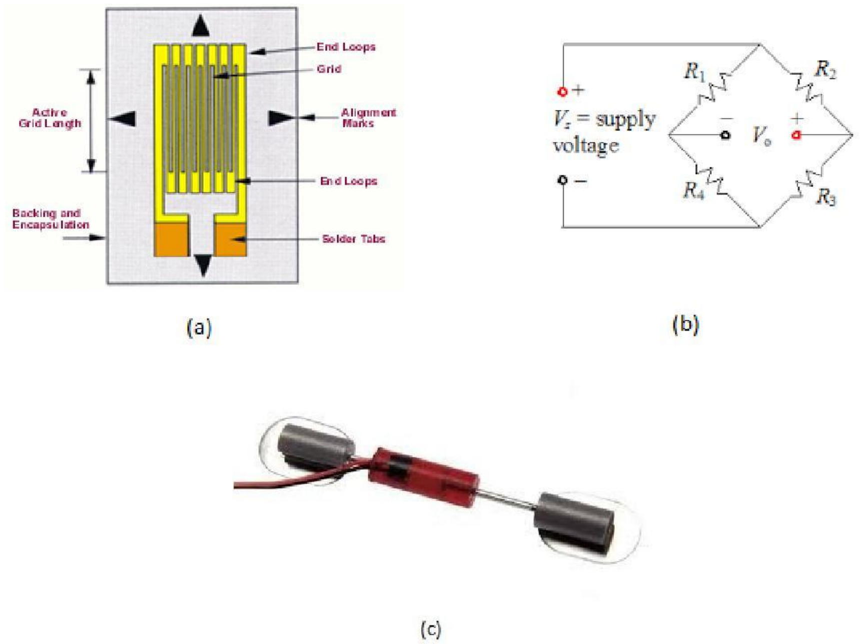


Figure 2.3: Types of Strain gages (a) Poiezoresistive (b) Wheatstone Bridge Circuit and (c) Vibrating Wire

2.2.2 Linear Variable Differential Transformers (LVDT)

An LVDT is a position sensor has two elements, a moving core and stationary coil assembly.Three types of LVDTs are unguided armature, captive armature, spring-extended armature.LVDTs are attractive for deteremine displacements for many reasons because there are no frictional forces to change the readings,there is no mechanical contact between the sens-ing elements and the sensors are highly robust due to no mechanical connection that cause fatigue failure.main darawback of LVDT is that its operating range is limited to its size only.

global properties.it measures dynamic response either its harmonic or transient.Drawbacks of accelerometer include high cost, bulkiness and susceptibility.

2.2.4 Potentiometer

Potentiometer come is many sizes and shapes but are typically worked on change in resistance to change in rotational or linear position string potentiometer have advantage over LVDT is that it can measure displacements that are larger than the sensor itself.

2.2.5 Anemometer

Anemometer used For large structures where wind speed can be of particular interest as it can be signicantly excite the structure.this is more critical for bridges as in which improper design can lead to self excitation as was the case with the famous to come narrow bridge. Different type of anemometers are exist but widely used is cup anemone meter. it is a drag driven device that turns because the drag on the smooth back surface on cup is less than that on the open face of cup this imbalance in drag results in rotational speed of the cup being proportional to the average wind speed.

2.2.6 Temperature Sensors

Which measures the effect of temperature on structures.temperature sensors are of four types that are described below:-

1. Expansion type
2. Resistance temperature detectors(RTD)
3. Thermistors
4. Thermocouple

2.2.7 Pressure transducer

These are used for measurement of preassure.These are of following types:-

1. Diaphragm type:- Measurement range 20-700 mpa upto 10kHz frequencies.
2. Qartz based:- Measurement range 20-700 mpa upto 200kHz frequencies.

2.3 Nano technology based CNT/cement composites

Due to limitations of the above methods and sensors of Structural Health Monitoring en-forced us to develop new sensors that are capable of determine accurate parameters that are essential for structural health monitoring . advancement of nano technology and nano materials have given a sensors named CNT/cement composite which are not accurate but also a cost effective and homogenous to concrete of having same strength that is comparable to concrete. Following literature review will brief us of recent research that has been happened on CNT/cement composites.

2.3.1 Fabrication of Carbon Nano tubes

In order to efficiently utilize carbon nanotubes and make use of their extraordinary properties, they should be well dispersed within the cement matrix. Dispersion of Carbon Nano Tubes (CNTs) means separating or spreading the tubes individually within the matrix by separating the agglomerations and bundles. Dispersion of Carbon Nano Tubes in cement was a main controlling factor in composite. Improper dispersion of these nano laments within the matrix effect the properties of composite. Carbon nanotubes in their dry state bundle together due to the vander Waals forces. These interfacial forces at the nano scale are strong enough to pull the nanotubes back to stick together, even after being dispersed in an aqueous solution. Chemical surfactants that provide non-covalent bonds have been used to reduce the surface tension of the solution and keep the Carbon Nano Tubes (CNTs) suspended and unbundled within the solution after they have been dispersed (separated) by mechanical dispersion. Regular hand soap is considered a good chemical surfactant for nano laments. Two main categories of dispersing techniques of nano laments have been used: mechanical dispersion and chemical treatment. A third technique that has been used to guarantee a good dispersion of Carbon Nano Tubes (CNTs) and CNFs within cement paste is growing Carbon Nano Tubes (CNTs)/CNFs directly on cement particle surfaces; in this method, the Carbon Nano Tubes (CNTs) are covered and attached on the surface of cement particles without the need for any further dispersion or sonication process.

2.3.1.1 Mechanical Dispersion of Carbon Nano Tubes (CNTs)

Mechanical dispersion alone using an ultrasonic wave mixer without any chemical surfactants is not effective for keeping Carbon Nano Tubes (CNTs) suspended and dispersed. However, mechanical dispersion is adequate to break the chemical forces between the Carbon Nano Tubes. Then it become easy to disperse in the aqueous solutions. The ultrasonic wave mixer or magnetic stirrer induces high energy into the solution with very high frequency waves (vibrations), causing micro and nano cavitation (vacuum bubbles) to be formed among the solution molecules. These micro/nano vacuum bubbles will implode when they touch the CNT surfaces. The imploded bubbles will cause a huge vacuuming force that will pull the nanotubes away into the solution; hence, the Carbon Nano Tubes (CNTs) will be separated from each other and in the liquid. However, if no surfactant is used in the solution, the suspended Carbon Nano Tubes (CNTs) will start to agglomerate and bundle again. In order to disperse the Carbon Nano Tubes (CNTs) effectively, sufficient energy and sonication time should be applied. If excessive amounts of energy, sonication time, or both are introduced into the CNT solution, the huge forces from the imploded micro bubbles will break (shorten) the nanotubes. Optimizing the sonication process will require providing the optimum combination of sonication energy, duration, volume of solution, concentration of nano laments, temperature, amount, and type of chemical surfactant (anionic, cationic, or nonionic) used in the solution.

2.3.1.2 Chemical Treatment of Carbon Nano Tubes (CNTs)

[Wang, 2006] The second technique is the chemical treatment of the surface of Carbon Nano Tubes (CNTs). This technique is widely used. Many different approaches have been used for chemical treatment (functionalization) of CNT surfaces, and many of them show good results in effectively dispersing Carbon Nano Tubes in the composite and improving bonding between the Carbon Nano Tubes and the surrounding material. Along with the mechanical dispersion of Carbon Nano Tubes (CNTs), the chemical treatment of the surface of Carbon Nano Tubes (CNTs) will help in improving the efficiency of dispersion and the bonding between the Carbon Nano Tubes (CNTs) and with the material matrix. There are two main types of chemical treatment: covalent bonding and non-covalent bonding (functionalization).

Non-Covalent Functionalization

The use of chemical surfactants in the sonication solution is the most common non-covalent functionalization approach. The existence of the surfactant will introduce non-covalent bond-ing or treatment for the CNT surface and the surrounding liquid. The main purpose of these chemical surfactants is to reduce the surface tension of the water, thereby helping to seprate the Carbon Nano Tubes (CNTs) and keep them suspended and separated within the solution [Moore, 2008] . The non-covalent functionalization approach gives the small amount of damage to the CNT surfaces since no defects are caused by the chemical surfactant to the CNTs and only damage (breakage) will be due to more sonication power induced.

Chemical surfactants are amphiphilic type which have two side groups in their structure i.e hydrophobic (non-polar) and hydrophilic (polar). The hydrophilic end group will be attached to water molecules.Where, The hydrophobic side of the amphiphilic surfactants will be attracted to the CNT surface (which is hydrophobic). Hence, the surfactant will pull the Carbon Nano Tubes (CNTs) away from each other toward the water in the aqueous solution and the nano laments will stay suspended in the solution because of these non-covalent bonds.

While the focus of this study was on the Carbon Nano Tubes (CNTs)/cement nanocompos-ites, it is important to mention that most of the CNT composite and dispersion research has focused on polymer nanocomposites. Many researchers have combined Carbon Nano Tubes (CNTs) within different types of polymers successfully. Many different chemicals have been utilized to disperse Carbon Nano Tubes within polymers. For example, Utrasonicated the carbon nano tubes in water with the addition of gum Arabic as surfactant for 20 minutes. They achieved homogeneous dispersions for the Carbon Nano Tubes (CNTs) because of the absorption of the surfactant. successfully dispersed high mass fractions of Carbon Nano Tubes (CNTs) in different surfactants like sodium dodecylbenzenesulfonate (NaDDBS)which is a main component of laundry detergentsTriton X-100, and sodium dodecyl sulphate (SDS). While these surfactants and many others can be used in polymers, there is a very limited number of surfactants options that can be used with cementitious materials. The nature and chemistry of cement and its hydration process require certain surfactants that are compatible with cement since many surfactants will slow down the hydration process of cement paste. It has been shown by that using sodium dodecylbenzenesulfonate as a surfactant with cement introduces much more air entrained in the cement paste (times more than normal range), thereby hindering the initial set of the cement paste for 24 hr. One of the most successful surfactants that is compatible with cement without affecting the hydration process was proposed by Yazdanbakhsh.

Covalent Functionalization

Covalent functionalization is widely used in the world of nanocomposites; it is not only a powerful tool for CNT and CNF dispersion but also opened the door to many applications of different nano composites by increasing the reactivity and bonding between functionalized Carbon Nano Tubes (CNTs) and the hosting matrix. Covalent functionalization has effectively utilized these nano laments into usable composite materials. Many different techniques have been used to functionalize Carbon Nano Tubes for homogenous dispersion of CNTs for the formation of CNT / cement composites, like acid treatment, Air oxidation, Plasma treatment, ozone treatment. The main purpose of these processes is to provide a side group (functional group) at the surface of Carbon Nano Tubes (CNTs).

The most common functional groups used in Carbon Nano Tubes (CNTs)/cement nanocomposites are the oxygen groups, which include hydroxyl, carboxyl, carbonyl, and ester side groups. Other side groups include halogen groups, like uoro and chloride side groups, in addition to hydrocarbyl groups, which include alkenyl and alkyl side groups. The functionalization of Carbon Nano Tubes (CNTs) targets one of the following locations of Carbon Nano Tubes (CNTs) that are the end caps, the defect sites, or the whole surfacewithout introducing defects sites on the surface (sidewall functionalization) [Xie, 2005] . The defect site functionalization includes using a strong oxidizing agent (like sulphuricacid) to attack and defect small locations of the CNTs. Usually a mixture of sulphuric and nitric acid is used for this type of function-alization. The level of functionalization depends on many factors, like the sulphuric/nitric acid ratio. The higher the concentration of the sulphuric acid, the more defects on the CNT surface. After that, the HNO_3 attracts with defected sites and attached the functional group to defected sites by covalent bonds [Chen, 2006] .

[Bandyopadhyaya, 2001] Functionalized Carbonator Tubes (CNTs) using sulfuric/nitric acid treatments. Carbon Nano Tubes (CNTs) were mixed with the solution of the sulfuric and nitric acid. Than solution was functionalized by microwave radiation at 450 W for 1 to 20 min at a pressure of 20 psi. The Raman and Fourier transformation infrared (RTIR) spectroscopy showed that the optimum microwave time was 3 min to prevent excessive damage of the Carbon Nano Tubes (CNTs). After drying the solution, SEM images were taken for the Carbon Nano Tubes (CNTs). Which is smaller than the original length of the Carbon Nano Tubes (CNTs). This indicates that the acid treatment along with the high energy of microwave radiations damaged the Carbon Nano Tubes (CNTs) and broke them into smaller pieces. [Kuznetsova, 2001] End cap functionalization is similar to defect site functionalization, but without using sulfuric acid to attack and defect the surface of CNTs. This means that the oxidizing agent interacts only with pre-defected locations. (if they exist) and functionalizes the end caps at the ends of the Carbon Nano Tubes (CNTs).

[Yazdanbakhsh, 2010] The last approach that is widely used for different types of nanocomposites is the sidewall functionalization. In this method, many different chemicals can be used to functionalize the surface of Carbon Nano Tubes (CNTs), but there is no need to use a strong acid for the functionalization [Huigang, 2007]. These chemicals include the use of salts like benzene diazonium salts, poleum (pyrosulfuric acid), or gases such as uorine gas.

Although it is very challenging to obtain good dispersion within cementitious composites, it is more challenging to evaluate quantitatively the level of dispersion of nano laments within many matrices, especially within cement paste. Only a few works have tried to quantitatively de ne the level of dispersion. However, experimentally,[Islam, 2003] SEM and TEM imaging could give some idea on how Carbon Nano Tubes (CNTs) are qualitatively dispersed within the matrix.

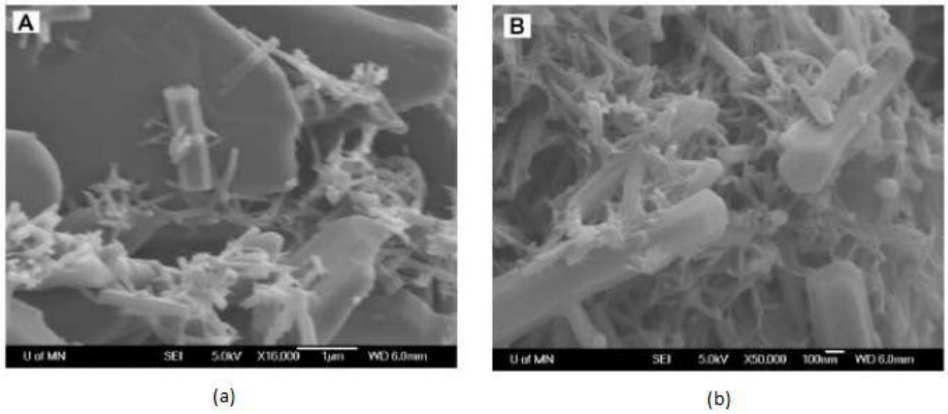


Figure 2.4: SEM pictures of CNT/cement composites after acids treatment. Untreated (left) and Treated (Right)

2.3.2 Electrodes

Four probe and two probe methods are used for resistance of composite by embedding four or two electrodes in composite respectively. In four probe or electrode method two electrodes are utilized for measuring voltage drop and two for passing current than resistance is determine by Ohms law. But in two electrode method resistance is directly measured from two electrodes with the help of digital millimeter. Both of method have their own importance as studied from the existing literature review. Hence concluded that four probe method is more accurate than two probe method.

2.3.3 Peizoresistivity

[yu, 2012] concluded that composite made by Acid treatment method has more piezoresistivity sensitivity than those from surfactant method. This variation in sensitivities among two composites made with different techniques due to the nano tube to nano tube interfaces. In the Covalant Functionalisation (Acid Treatment), CNTs are missed in cement without any chemical.Thats why the then no tubes could attract directly with each other in the Carbon nano tube network .But in the Non covalant functionalisation (surfactant), the nano tube surfaces are covered with surfactants (SDS). Therefore, surfactant can act as barrier. between nanotubes, which reduces the piezoresistivity response levels.

Authors also studied the resistances of composites fabricate with different water concentration and their responses to loading in their research. For this study, they used CNT with 0.1% by wt. of cement at three different w/c ratio i.e. 0.1%, 3.3% and 9.9%.They have noted that the piezoresistivity of the composites does not changes linearly with the increasing water concentration, but the conductivity Increases with water concentration. [Sun, 2013] in the paper entitled SHM with Nano Cement based Sensors presented that compressive strength of

CNT based cylinderical cement paste composite with different composition of CNT increases by 20-30% than plane cement and CNF specimen.

[JingXu, 2014] in the paper entitled Nano technology based system for damage resistant concrete pavement concluded that With CNF 0.1% by wt. of cement,fracture toughness, exure, strain capacity increased by 252%, 81%,139%. A SEM pictures was taken to see the pullout of ber.

[jun,2008] concluded that CNT/cement composites have better sensitivities in held also. These sensors give better results as compared to strain gauges by performing a held experiment on road pavement.

[Fu X, 2013] Authors also studied that resistances of CNT/cement composites with variation of CNT concenterations and their responses to loading in their research. For this study, authors used CNT with 0.05% by wt. of cement, 0.1% by wt. of cement, 1% by wt. of cement at W/C ration 0.45. Authors noted that piezoresistivity of the composites does not changes linearly with varied CNT concentration, but the electrical conductivity Increases with CNT concentration.

[Wang and others, 2013] concluded that Mixing of treated CNTS in cement enhance the toughness of composite. With the addition of CNTs improved the toughness index by 58 % and porosity reduces by almost 13%. it also improves the fracture energy to maximum by 313 N/m and pore sizes reduced to 21% with the addition of 0.09 % of CNTs by wt of cement.CNT forms the bridges across the cracks and transfer the load in tension without rupture failure.

CHAPTER 3

EXPERIMENTAL PROCEDURE: MATERIALS & METHODS

3.1 Materials

Cement

In this study, the cement used is Portland cement of grade 43 conforming to IS 8112 Produced ACC Limited. The physical properties of Cement are listed in Table 3.1.

Table 3.1: Physical Properties of Cement

Parameters	Test Results	Standard
Specific Gravity	3.15	
Initial Setting Time	40 min	>30 min
Final Setting Time	8 hrs	<10 hrs

Coarse Aggregate

In general,Size of aggregate determines the workability of concrete because workability is proportional to the size of aggregate.it increases with the size of aggregate.Maximum size of aggregate that we used is upto 20mm conforming to IS 456:2000 and IS 1343:1980.

Fine Aggregate

The new aggregates was used of newness modulus 2.89 obtained by sieve analysis.

Carbon Nano Tubes (CNTs)

The used carboxyl group functionalized MWNTs provided by United Nanotech Innovations Pvt. Ltd., India. Their main properties are given in Table 3.2 and detail parameters are described in annexure.

Figure 3.1: Carbon Nano Tubes

Table 3.2: Properties of CNTs

Parameters	Value
density	2.1 gm/cm^3
Type	MWNT
Functionalised Group	Carboxyl
Length	10-30 m
Purity	98%
Ash	< 1.5 wt.%
density	2.1 gm/cm^3
Poison ration	0.16

3.2 Preperation of CNT/cement Composites

3.2.1 Dispersion of CNT in water

According to previous studies Acid treated CNTs are higher sensitive to piezoresistivity than non covalant functionalisation.So we used Carboxyl group CNTs in this research that we got

Directly manufacture because carboxyl group functionalized CNTs contain oxygen atom at there end which create repulsive forces between CNTs. So that they easily dispersed. Acid treated Multi wall carbon nano tubes that we got from manufacturer, rashly dispersed in ethanol (50 ml) for 40-50 minutes with the help of jar test apparatus shown in the following picture to form homogenous solution.

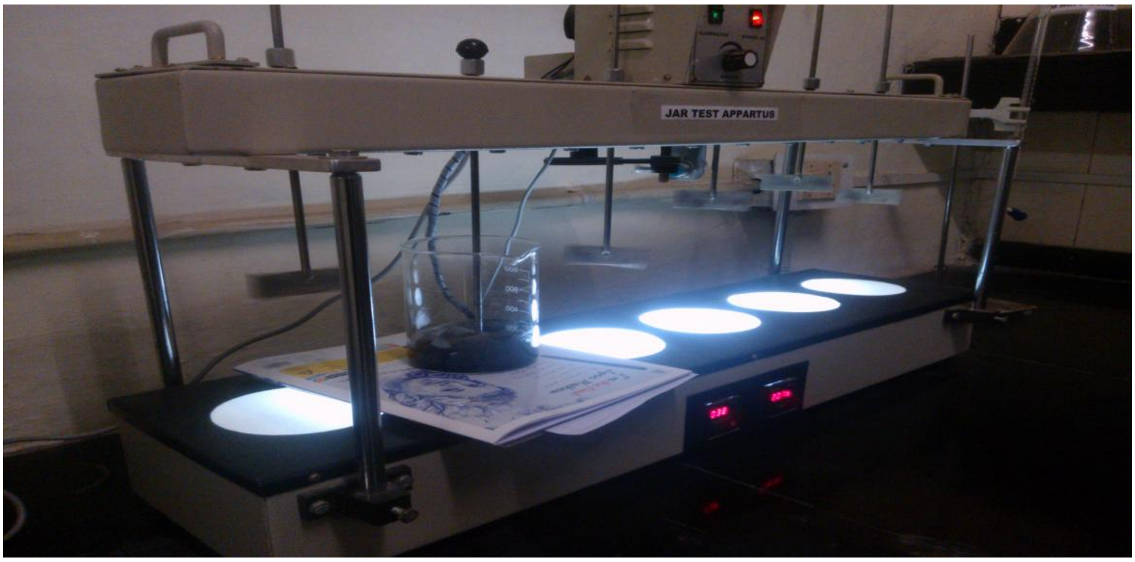


Figure 3.2: Dispersion of CNT with Jar test Apparatus.

3.2.2 Preperation of Electrodes

1. Firstly construct the wooden frame of size of 450 x 260 mm.
2. Than place the nails at 17mm and 12mm intervals along length and width respectively.
3. Than wind the 28 gage copper wire from the top leg to bottom leg to all nails of wooden frame along length.
4. Than wind the 28 gage copper wire from the right leg to left leg of wooden frame to all nails along length.
5. Than solder the each junction where horizontal and vertical wires cross each other
6. Than cut the pieces of copper wire mesh of size from master wire mesh.

Figure 3.3: Schematic procedure To prepare elctrodes

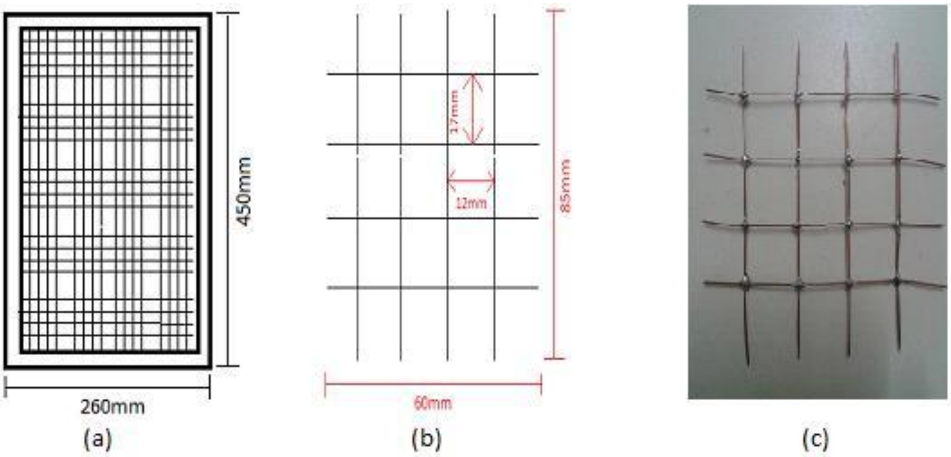


Figure 3.4: Dimesions and Layout of electrodes

3.2.3 Casting of Cubes

Homogenous solution of Dispersed CNTs in water mixed with cement without course or ne aggregate. The CNT/cement pastes were molded into 70.8 x 70.8 x 70.8 mm^3 shapes.Than two electrodes are inserted with 1 cm apart. After that compaction was done with electric vibrator.Sample was demolded in one day, cured for 28 days and then dried in an oven before testing.following table shows the different samples of composites with variation of materials to get the more sensitive sensor.

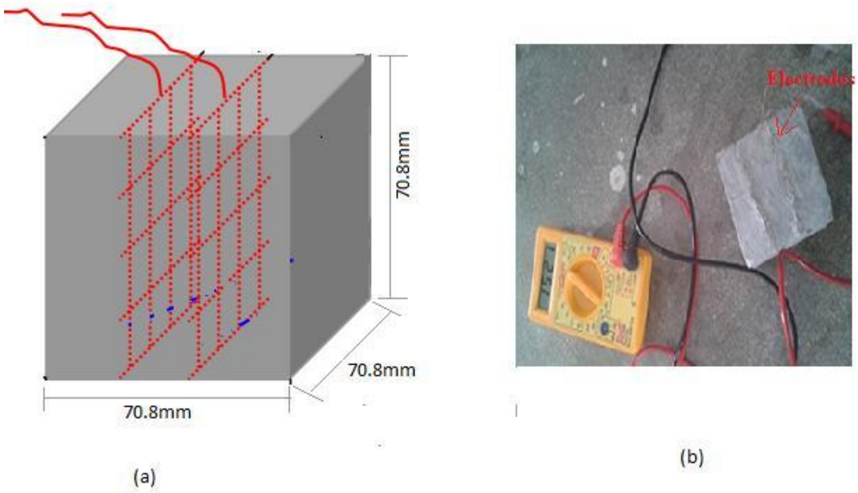


Figure 3.5: Schematic picture of cube with Electrode

3.3 Mix proportions CNT/cement composites

To analyses the effect of Carbon Nano Tube(CNTs) concentration and water on the piezoresistivity , sample of CNTs/cement composite with varied concentration level of CNTs and at different water content are fabricated .Following tables shows different type of mix proportion that require for study.

Table 3.3: Mix Proportion of CNT/cement composites at different CNT conc. levels

Sample	CNT/cement
1	0.05 %
2	0.1 %
3	1 %

Table 3.4: Mix Proportion of CNT/cement composites at different water Content

Sample	Increase of water of 0.40
1	5%
2	10%
3	20%

3.4 Design of Beams

Beam is designed to take Ultimate Load of 60KN at the center of beam with fck = 25N= mm^2 and fy = 500N= mm^2.Mix Proportions are shown in below table. Parameters of Designed Beam are in following Table 3.3

Table 3.5: Mix Proportion of Concrete in kg= m^3

Parameter	Strength Grade	Cement	W/C	Sand	Coarse Aggregate
value(in mm)	M25	418	0.55	617	1245

Table 3.6: Parameters of beam

Parameter	b	d	l	l1	upper bar	under bar	hooping
value(in mm)	150	190	1000	900	2 8	2 12	8 150

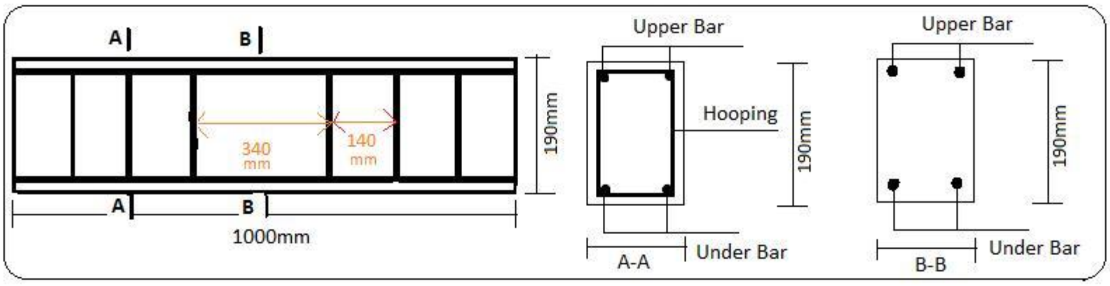


Figure 3.6: Layout of Beam with reinforcement

3.5 Casting and placing of sensors

To check the applicability of sensor in the held three beams are casted with the embeddment of these sensors named CBCC-1, CBCC-2, CBCC-3 at three critical zones i.e Compression zones, Biaxial Compression and Shear tension zone respectively. Exact Placement of sensors also shown in following table.

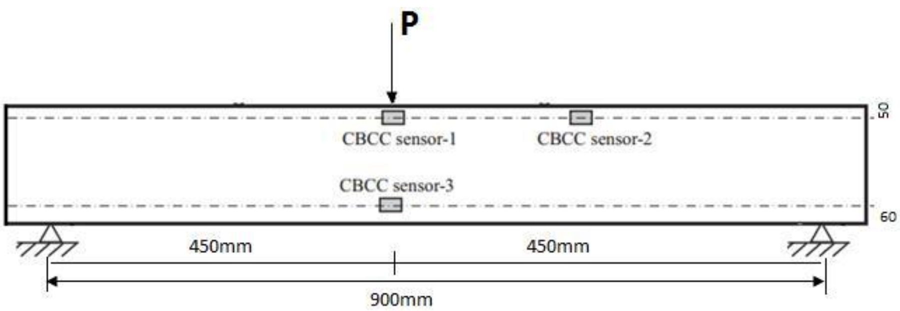


Figure 3.7: Layout of sensors in beam

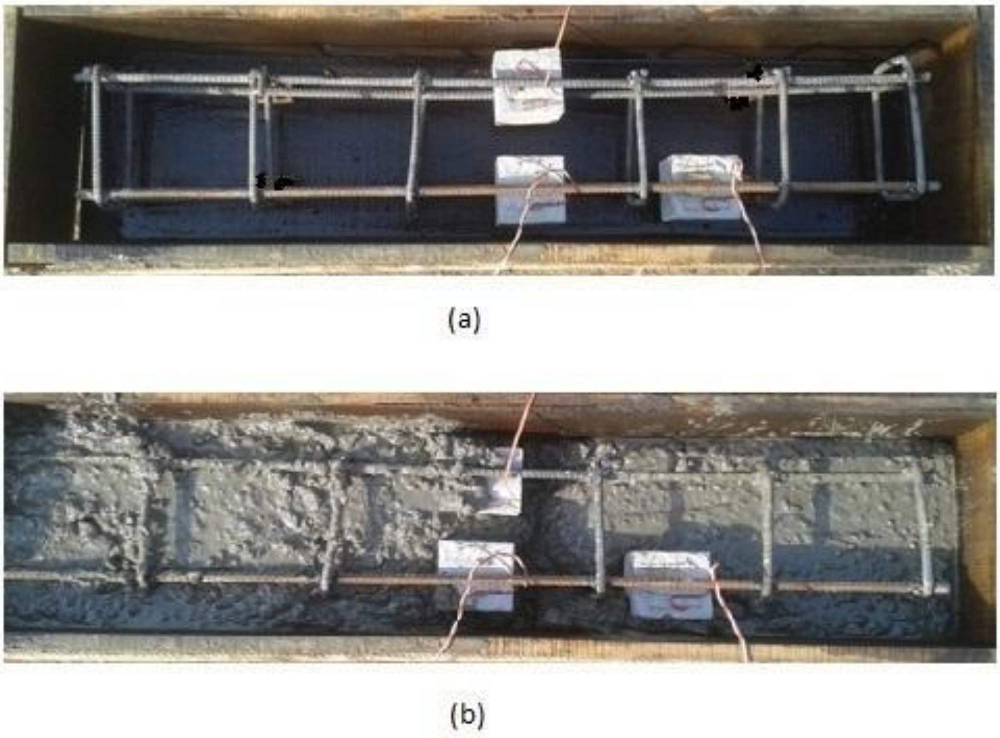


Figure 3.8: Casting of beams

3.6 Experimental setup

To measure the piezoresistivity of the composites, samples were tested in compression testing machine in Concrete lab, JUIT. Experimental setup is shown in fig. Loads were applied Prependicular to plain of electrodes.Than electrical resistance was measured by two probe method with the help of digital millimeter.

Figure 3.9: Laboratory setup to measure piezoresitivity

3.7 3 point bending testing under UTM

Now the beams are tested under 3 point bending exure on UTM after placing the beam on span of 960mm.Now the load is applied by plunger at the center of beam and the resistances are noted down from digital millimeter correspond to the loading.

Figure 3.10: Beam testing under UTM

CHAPTER 4

RESULTS AND ANALYSIS

4.1 Effect of CNT concentration on Piezoresistivity of composite

Graphs will show the effect of CNT concentration on piezoresitive sensitivity of CNT/cement composite. To check piezoresistivity of composite apply a repeated load of 8Mpa at regular intervals.

Observation Table

Table 4.1: Variation of resistance at different CNT concentration levels

Stress	0.05% MWNT			0.1% MWNT			1% MWNT		
Mpa	R_i	R_t	R	R_i	R_t	R	R_i	R_t	R
8.1	1977	1813	-164	1821	1328	-193	1430	1345	-85
16.25	1977	1690	-287	1821	1174	-347	1430	1249	-181
24.12	1977	1514	-463	1821	986	-535	1430	1161	-269
32.4	1977	1365	-612	1821	783	-738	1430	1084	-346

4.1.1 Result

Variation of Change in resistance Under 8Mpa at 0.05% CNT

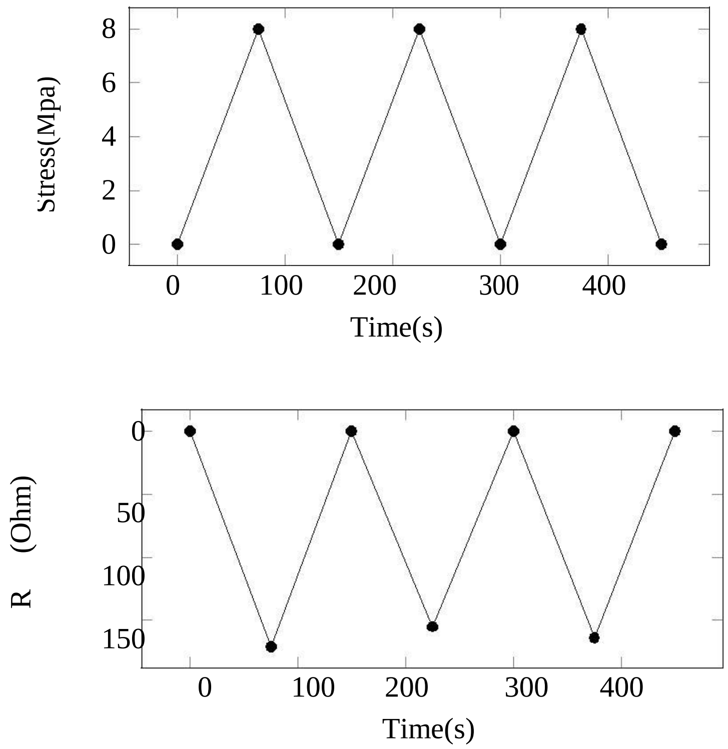


Figure 4.1: Comparison of change in resistance under repeated loading of 8 Mpa

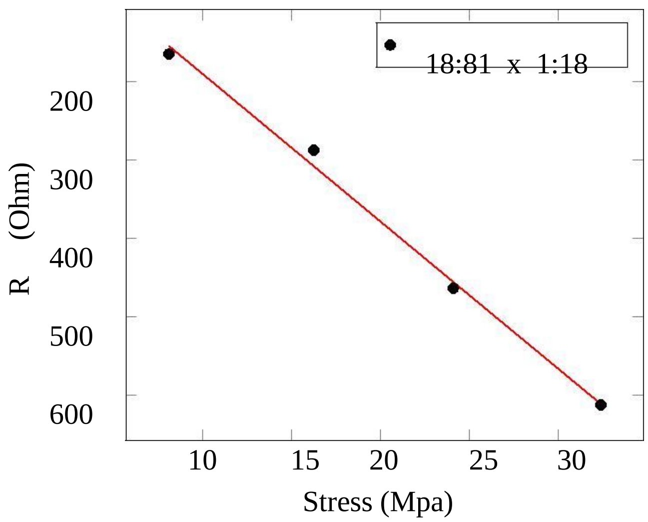


Figure 4.2: Change in resistance vs stress at 0.05 % CNT

Variation of Change in resistance Under 8Mpa at 0.1% CNT

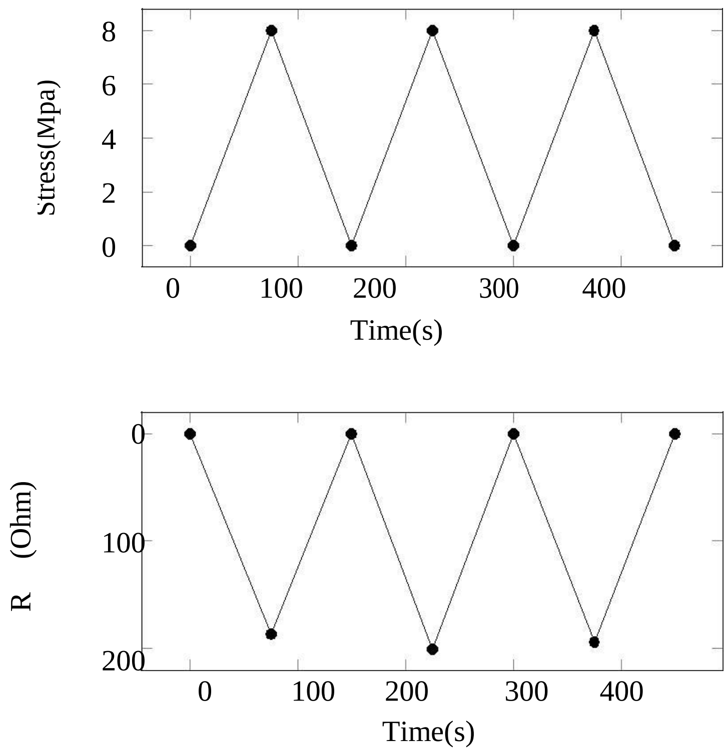


Figure 4.3: Comparison of change in resistance under repeated loading of 8 Mpa

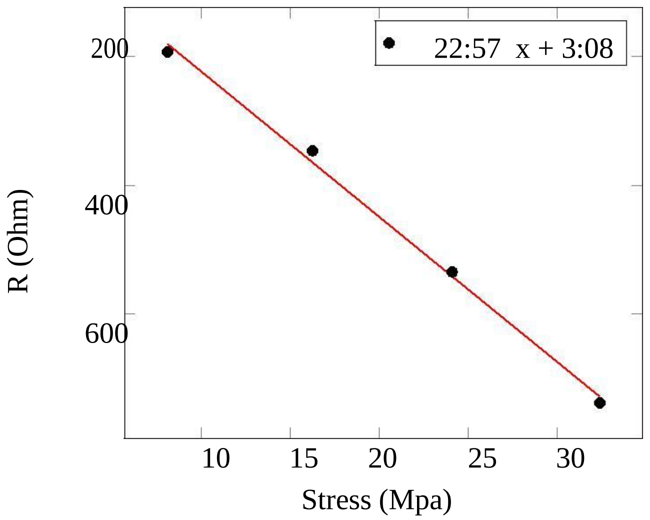


Figure 4.4: Change in resistance vs stress at 0.1 % CNT

Variation of Change in resistance Under 8Mpa at 1% CNT

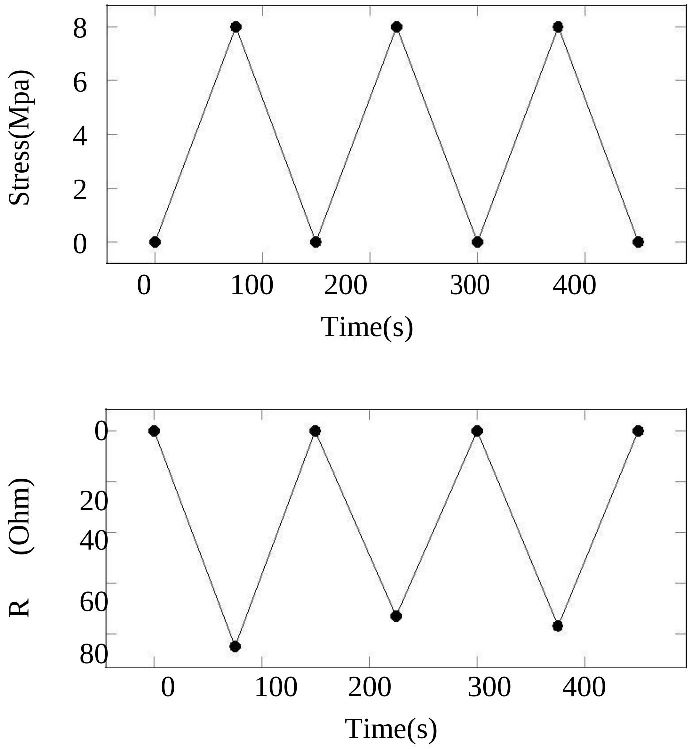


Figure 4.5: Comparison of change in resistance under repeated loading of 8 Mpa

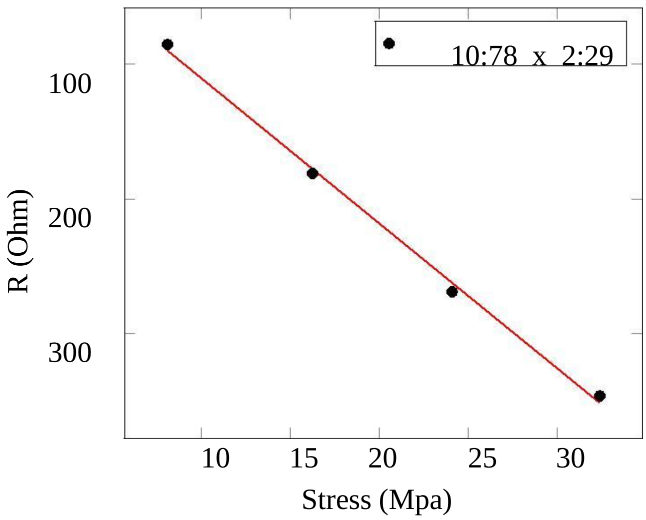


Figure 4.6: Change in resistance vs stress at 1 % CNT

4.1.2 Discussion

Above graphs shows that piezoresitive responses under repeated compressive loading with the stress of 8MPa at samples of different CNT concentration levels. The resistance of all the three types of samples or composites decreases upon loading and increasing on unload-ing under every repeated compressive loading which expresses the stable, linear and regular piezoresistivity responses.

4.1.3 Comparison

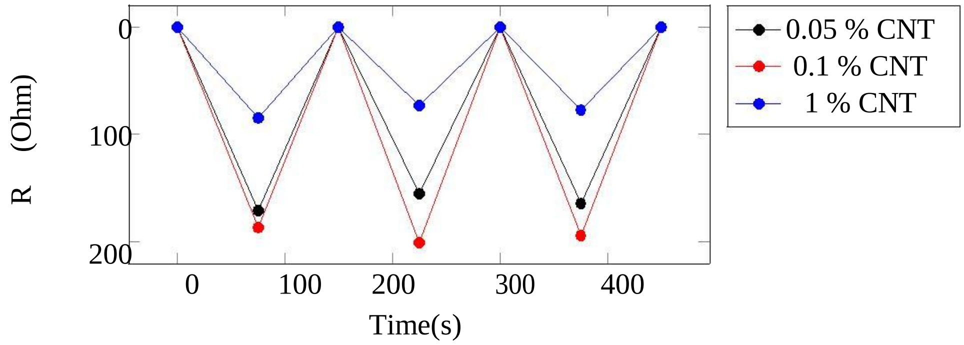


Figure 4.7: Comparison of magnitude of R under repeated loading of 8 Mpa at different CNT concentration

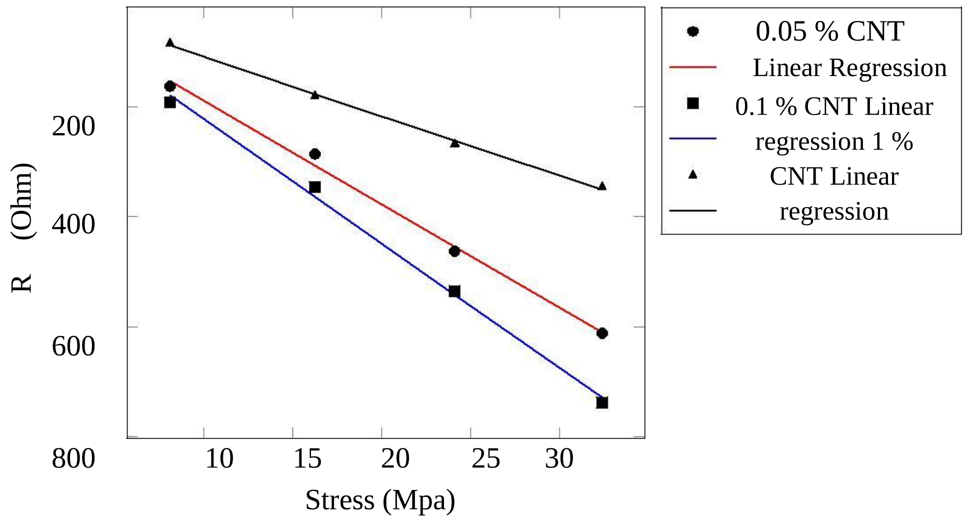


Figure 4.8: Comparison of R vs. Stress at different CNT concentration

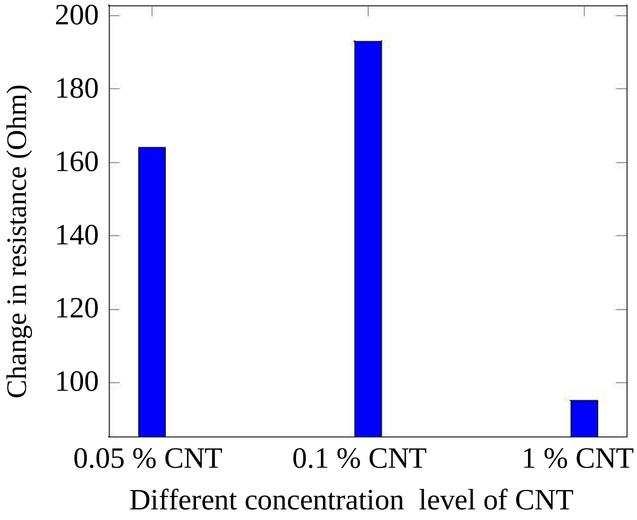
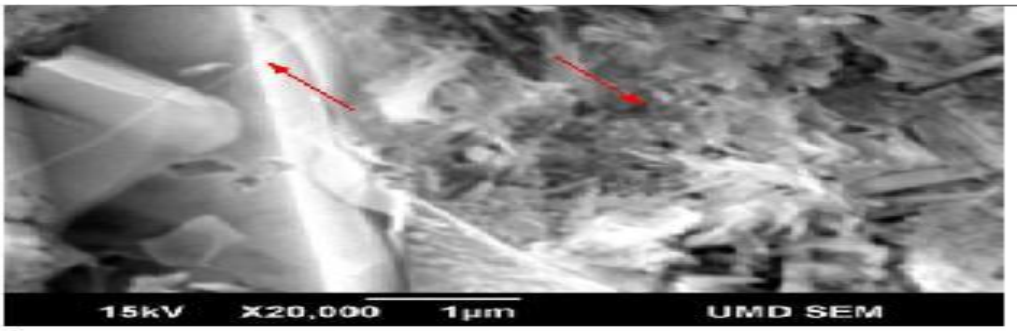


Figure 4.9: Comparison of sensitivity of piezoresitivity at different CNT concentration levels

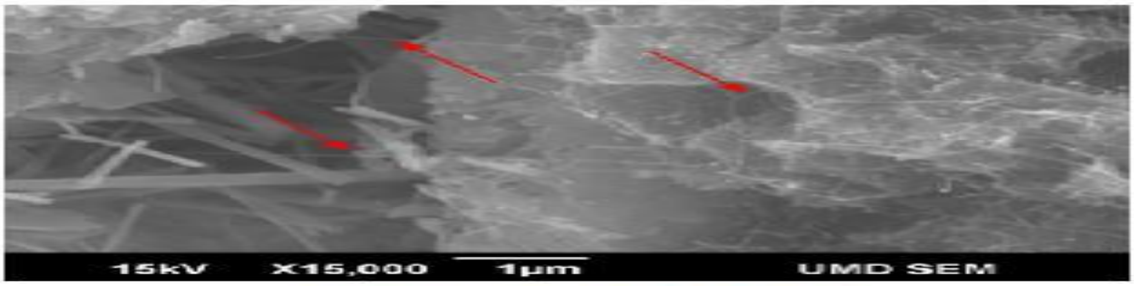
Discussion

From the bar graphs we examined that the magnitude of varied resistances reaches to 164 , 193 and 95 at different CNT concentrations i.e 0.05%, 0.1%and 1% respectively under repeated loading of magnitude 8Mpa. from the above results we analyses that varied resistance is more at 0.1% among other composites.

This happen because when the CNT concentration is low than distance between two adjacent CNT is high which reduced the amount of conducted tunneling junction. As we increasing the CNT concentration distance between two adjacent CNT reduces and enhances the tunnel-ing conduction which reduces resistivity and increasing the conductivity. With the continues increase of CNT, tunneling gap further shortened and CNT network stabilized at that point and it become hardly to change the resistance at i.e 1%(by wt. of cement) CNT. thats why the trend of change in resistance is not linear with the increase of CNT concentration, First it increase than it decreases. Even SEM pictures also shows that at 1% (by wt. of cement)CNT are more widely spread than at 0.01% (by wt. of cement)CNT.



(a)With 0.1% wt of MWNT



(b)With 1% wt of MWNT

Figure 4.10: SEM pictures of CNT/cement composites

4.2 Effect of water content on Piezoresistivity

From the above discussion we conclude that Piezoresistivity of composite at 0.1 % (by wt. of cement) MWNT is more .so we take as this the optimize value from the above samples .now we check the effect of water content on this CNT concentration level by increasing water content by 5%, 10%, and 20% of the above optimized composite. following graph will shows the behaviour of piezoresistivity at different water content.

Observation Table

Table 4.2: Variation of resistance at different water conc. levels

Stress	at 5% increase			at 10% increase			at 20% increase		
Mpa	R_i	R_t	R	R_i	R_t	R	R_i	R_t	R
8.1	1752	1541	-211	1536	1279	-257	1153	1043	-110
16.25	1752	1343	-409	1536	1009	-527	1153	948	-205
24.12	1752	1138	-614	1536	771	-765	1153	852	-301
32.4	1752	914	-838	1536	533	-1003	1153	754	-399

4.2.1 Results

Variation of piezoresistivity at 5 % increase of water

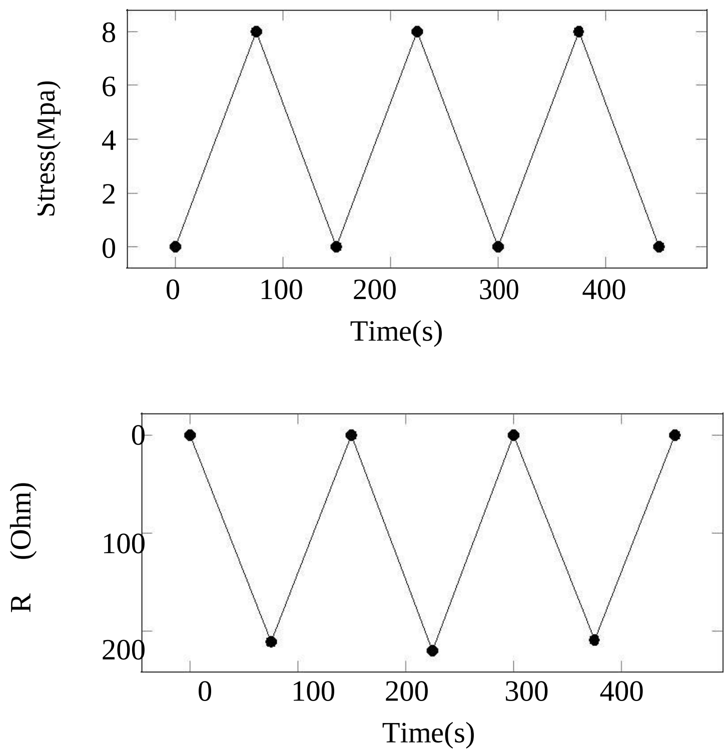


Figure 4.11: Comparison of change in resistance under repeated loading of 8 Mpa

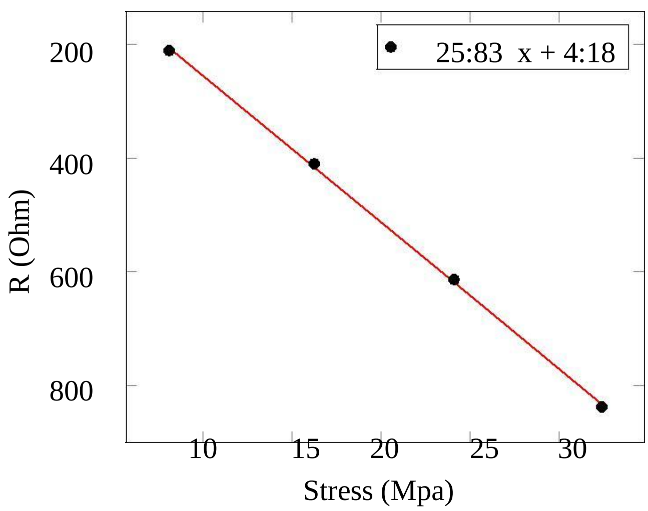


Figure 4.12: Change in resistance vs stress at 5 % increase of water

Variation of piezoresistivity at 10 % increase of water

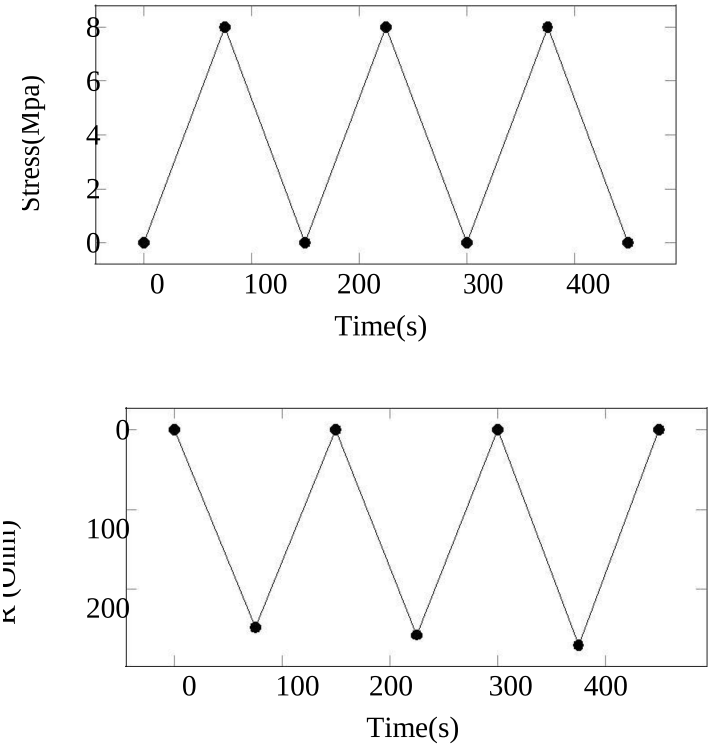


Figure 4.13: Comparison of change in resistance under repeated loading of 8 Mpa

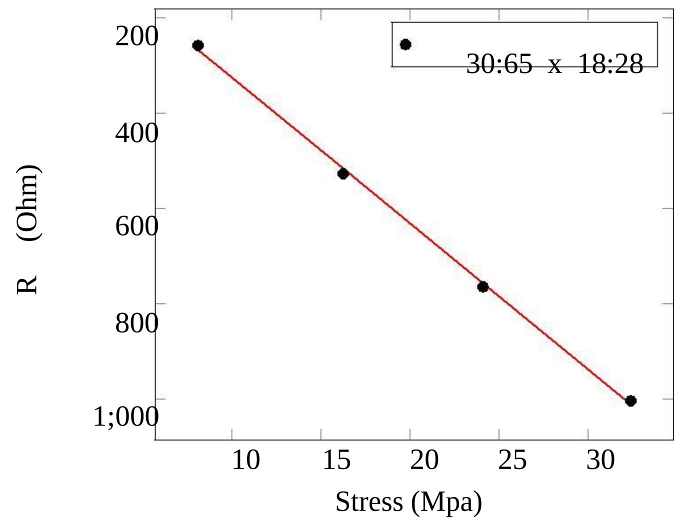


Figure 4.14: Change in resistance vs stress at 10 %increase of water

Variation of piezoresistivity at 20 % increase of water

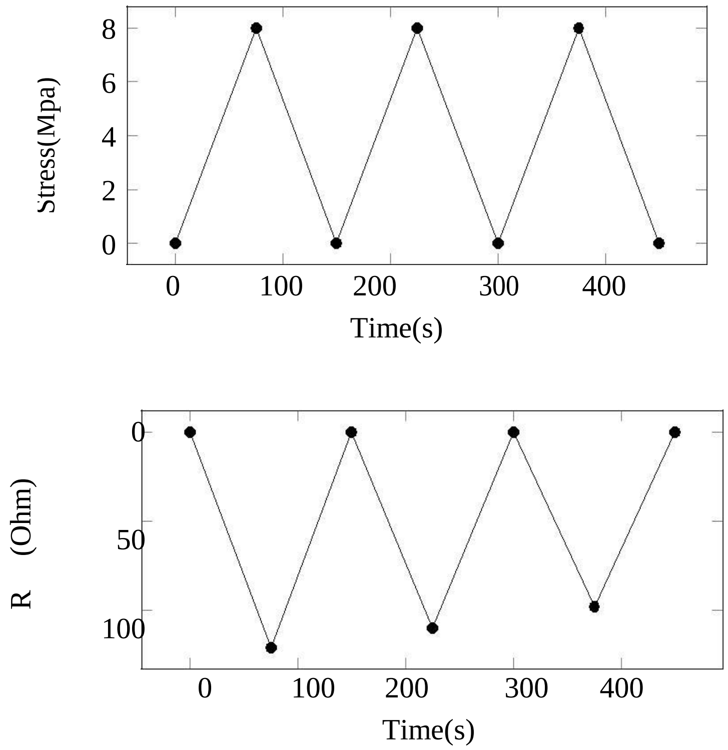


Figure 4.15: Comparison of change in resistance under repeated loading of 8 Mpa

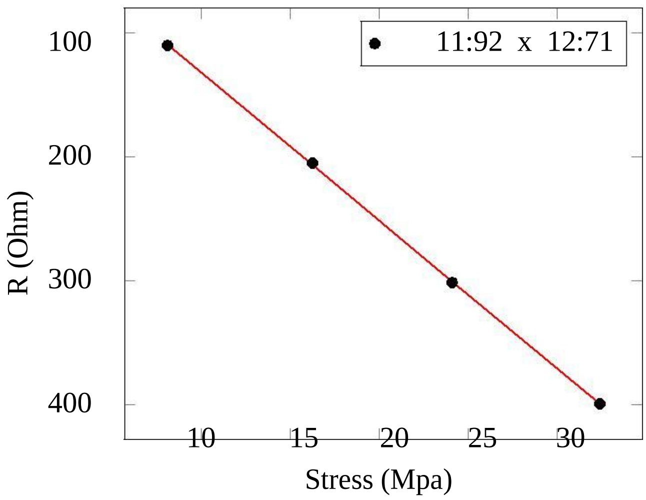


Figure 4.16: Change in resistance vs stress at 20 % increase of water

4.2.2 Comparison

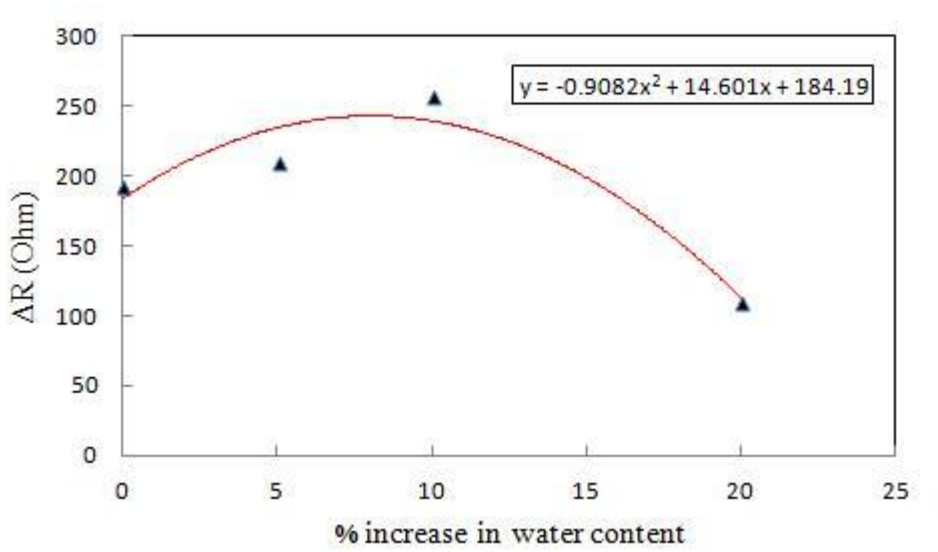


Figure 4.17: Change in resistance vs % increase of water

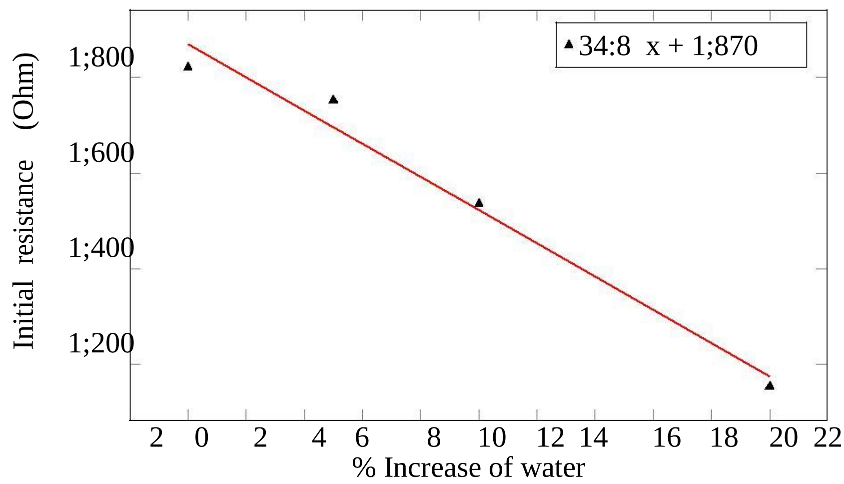


Figure 4.18: Initial resistance vs % increase in water

4.2.3 Discussion

From the graphs we anlyse that variation in resistance is not linear with the increasing water content. But the initial resistance reduces which cause the increase in conductivity.

There are two criterias that are responsible for this .One is electrical conductivity and the other is Field emission effect on the end of nanotube both these factors can be enhanced by adsorption of water molecules. With the increase of water content adsorption of water molecule increases which increses the held emission and electrical conductivity which caused reduction of tunneling gap and increases tunneling conduction .But at some stage network stabilised and become hardly to change resistance i.e at increase of 20 % water under the external loading. Thats why Composite at 10% increase of water are more sensitive among the other composites. But the conductivity increases with the water content.

4.3 Analysis of Beam

Given:-

b=150mm

d=190mm

f_y = 500 N=mm^2

f_{ck} = 25 N=mm^2

Dia of bar = 12mm

No of bars=2

Sollution

$A_{st}=2 \quad {}_4\,(12)^2 = 226.08mm^2$

$p_t = \frac{A_{st}}{bd} = .00793$

For Fe 500 steel bars,f_y = 500 N=mm^2.For M 25 concrete,f_{ck} = 25 N=mm^2.

Hence, $\frac{x_u}{d} = 2.417\, p_t \frac{f_y}{f_{ck}} = 2.417 \; .00793 \; \frac{500}{25} = 0.383$

The limiting value of $\frac{x_u}{d}$ is given by following

$$\frac{x_{u;max}}{d} = \frac{700}{1100+0{:}87 \;\; 500} = 0.456$$

Thus the actual N.A depth is less than the limiting one . Such a beam is under-reinforced.

The Ultimate Moment of resistance is given by:-

$M_u = 0.87 \; f_y \; d\,(1-\frac{f_y A_{st}}{f_{ck} b d}) = 0.87 \; 500 \; 226.08 \; 190\,(1-\frac{500 \; 226.08}{25 \; 150 \; 190})$

$M_u = 15.72 \; 10^6$ N-mm.

$M_{u;lim} = 0.37 \; 25 \; 0.456\,(1-0.416 \; 0.456)150\,(190)^2 = M_{u;lim} = 18 \; 10^6$ N-mm.

Hence, M_u is less than $M_{u;lim}$. it is safe.

4.3.1 Specification of sensor

Curve predicts the Variation of deflection with Piezoresitivity Which were obtained From optimised CNT/cement.That will help us to and deflection at the center of beam under loading. Following Table will predict the specification of CNT/cement composite.

Table 4.3: Specification of sensor

Relation	CNT/cement %	W/C %	Treatment	b_1 mm	d_1 mm
stress= -0.003 R - 0.1266	0.1	0.44	Acid Treated	70.8	70.8

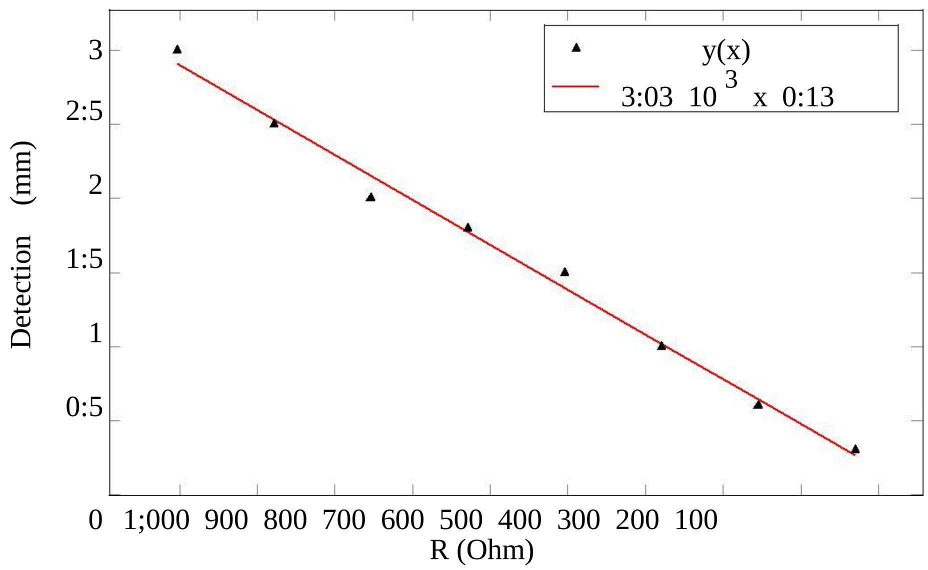


Figure 4.19: Curve between Change in resistance vs Deflection obtained from composite

4.4 Comparison of deflection at the center of beam measure by CBCC-1 and Dial gauge

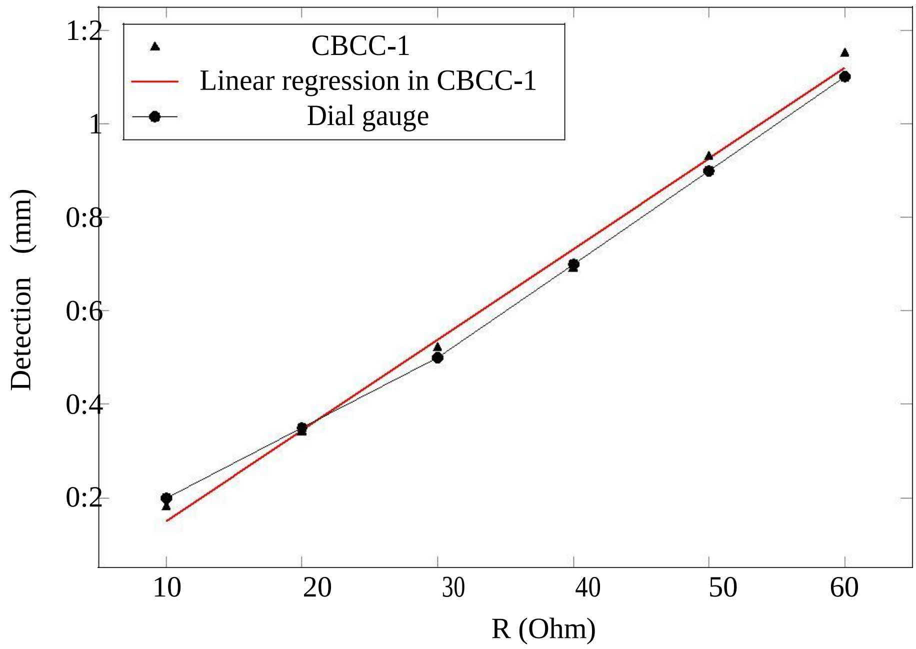


Figure 4.20: Comparison of Dial gauge and CBCC-1 for calculating deflection at the center of beam

4.5 Determination of stress

Bending Stress are determine by Bending Equation as follows:-

$$\frac{M}{I} = \frac{}{y} = \frac{E}{R}$$

Shear stresses are determine by :-

$$= \frac{F}{2I}\left(\frac{d^2}{4} - y^2\right)$$

4.5.1 Theoretical stresses

Table 4.4: Compressive stresses under different loading at CBCC sensor-1

Load (W) Kn	Span(L) m	Moment ($M=\frac{WL}{4}$) Kn-m	M.O.I ($I=\frac{bd^3}{12}$) m^4	Y m	Compressive stress (Mpa)
10	0.9	2.25	.0.0000857	0.022	0.57
20	0.9	4.5	0.0000857	0.022	1.15
30	0.9	6.75	0.0000857	0.022	1.7
40	0.9	9	0.0000857	0.022	2.33
50	0.9	11.25	0.0000857	0.022	2.9
60	0.9	13.5	0.0000857	0.022	3.5

Table 4.5: Compressive and shear stresses at CBCC sensor-2

Load (W) Kn	Span(L) m	Shear Force Kn	Y m	Shear ( ) stress (Mpa)	Compressive stress (Mpa)	Resultant stress (Mpa)
10	0.9	5	0.022	0.17	0.269	0.32
20	0.9	10	0.022	0.34	0.54	0.64
30	0.9	15	0.022	0.51	0.81	0.96
40	0.9	20	0.022	0.68	1.08	1.3
50	0.9	25	0.022	0.85	1.3	1.62
60	0.9	30	0.022	1.02	1.6	1.89

Table 4.6: Tensile stresses under different loading at CBCC sensor-3

Load (W) Kn	Span(L) m	Moment ($M=\frac{WL}{4}$) Kn-m	M.O.I ($I=\frac{bd^3}{12}$) m^4	Y m	Tensile stress (Mpa)
10	0.9	2.25	.0.0000857	0.058	1.52
20	0.9	4.5	0.0000857	0.058	3.04
30	0.9	6.75	0.0000857	0.058	4.6
40	0.9	9	0.0000857	0.058	6.1
50	0.9	11.25	0.0000857	0.058	7.63
60	0.9	13.5	0.0000857	0.058	9

4.5.2 Experimental Stresses

Following curve predict the Variation of Stresses with Piezoresitivity Which were obtained From optimized CNT/cement composite under different stresses .That will help us to nd stresses in beam under loading. Following Table will predict the specification of CNT/cement composite.

Table 4.7: Specification of sensor

Relation	CNT/cement %	W/C %	Treatment	b_1 mm	d_1 mm
stress= -0.0321 R - 0.149	0.1	0.44	Acid Treated	70.8	70.8

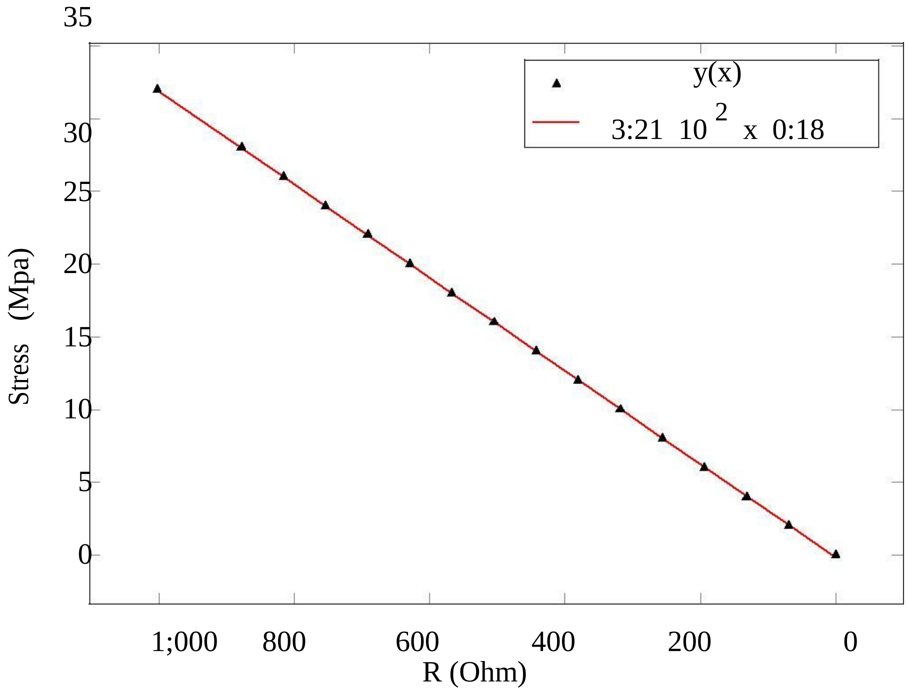


Figure 4.21: Curve between stress and change in resistance of CNT/cement composite

Table 4.8: Experimental stresses from curve

Load (W)	CBCC-1		CBCC-2		CBCC-3	
Kn	R	Stress (MPa)	R	Stress (MPa)	R	Stress (MPa)
10	-28	0.65	-19	0.39	-60	1.83
20	-4971.27	-30	0.76	-110	3.11	
30	-67	1.84	-36	0.97	-163	5.39
40	-85	2.44	-50	1.39	-212	6.77
50	-107	3.15	-60	1.69	-263	8.27
60	-116	3.52	-71	2.09	-390	9.86

4.6 Comparison of Theoretical stresses and Experimental stresses

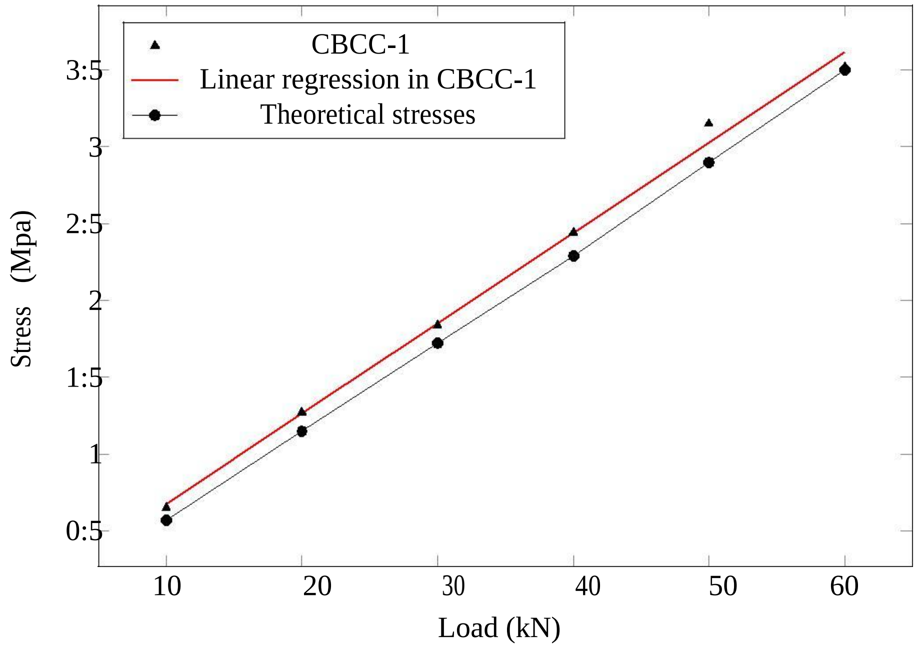


Figure 4.22: Comparison of theoretical and experimental compressive stress from CBCC-1

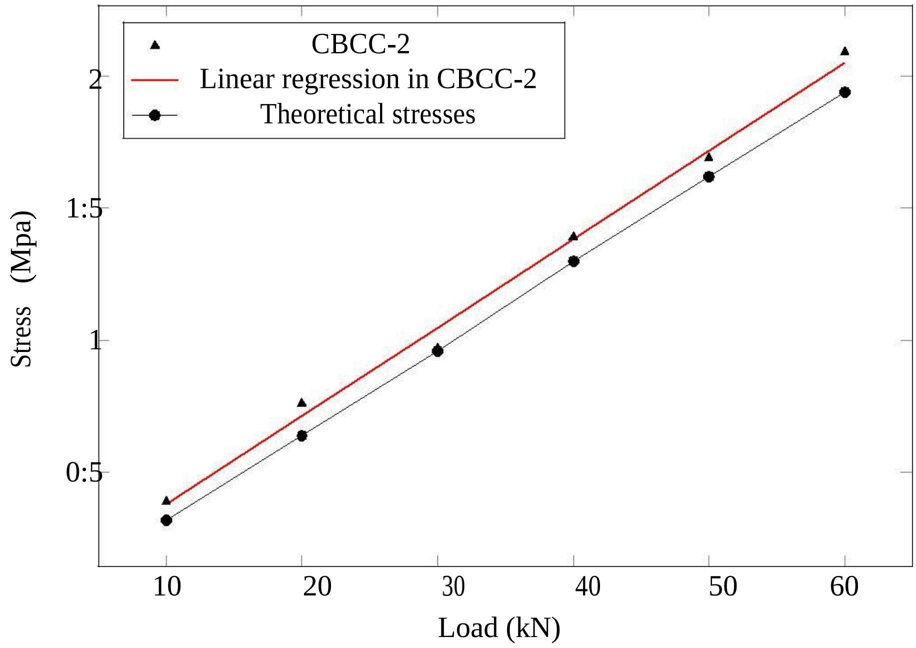


Figure 4.23: Comparison of theoretical and experimental Compressive and shear stress from CBCC-2

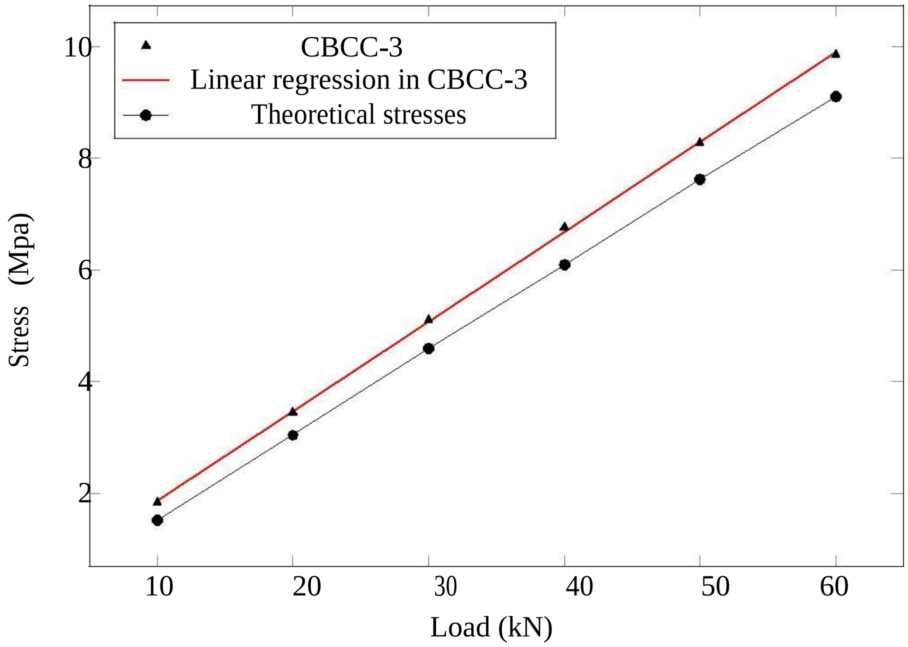


Figure 4.24: Comparison of theoretical and experimental tensile stress from CBCC-3

4.7 Accuracy of sensors:-

CBCC-1

Avg. Theoretical stress=2.02 Mpa

Avg .Experimental stress=2.14 Mpa

Error=6-6.47=-0.12Mpa

% Error=$\frac{0.12}{2.02}$ 100 = 5.9 %

% Accuracy=100-5.9=94.1%

CBCC-2

Avg. Theoretical stress=1.113 Mpa

Avg. Experimental stress=1.215 Mpa

Error=4.015-4.08=-.102Mpa

% Error=$\frac{0.102}{1.113}$ 100 = 9.16 %

% Accuracy=100-9.16=90.84%

CBCC-3

Avg. Theoretical stress=5.33 Mpa

Avg. Experimental stress=5.88 Mpa

Error=16.90-16.535=.55 Mpa

% Error=$\frac{0:55}{5:33}$ 100 = 10.31 %

% Accuracy=100-10.31=89.69%

4.7.1 Discussion

From the result we analyse that CBCC-1 censor give more accurate result that other and CBCC-3 gives less accuracy because of small tensile strength and deformation capacity of cement composite . Accuracy of above censors is 85-95%.

CHAPTER 5

CONCLUSIONS

CNT / cement composites were fabricated and tested in this research. Tests were performed to check the sensitivity of the CNT / cement composite under repeated compressive Loading of 8Mpa and these sensors were embedded in beam to check its applicability in the held.

1. Piezoresistivity under repeated compressive loading with the stress of 8MPa are stable, linear and regular.

2. Piezoresistivity of CNT/cement composite not changes linearly with the increase of CNT concentration and water content. It rst increases and than decreases and these results are varied with Existing Literature review.

3. CNT / cement composite shows a precise result than dial gauge in the measurement of center deflection of beam.

4. Piezoresistive CNT/cement composite gives a compressive ,tensile and compressive and shear stress with a accuracy of 85-95 % of theoretical results with the embedment of CNT/cement composites at three stressed zone that are uniaxial compression ,uniaxial tension and biaxial compression and shear.

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