MEASURMENT OF ELECTRICAL CONDUCTIVITY OF NATURAL FIBER COMPOSITE

BACHELOR OF TECHNOLOGY

IN

MECHANICAL ENGINEERING

BY

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This is to certify that the thesis entitled " **MEASURMENT OF ELECTRICAL CONDUCTIVITY OF NATURAL FIBER COMPOSITE** " submitted to National Institute of Technology, Rourkela by **GAUTAM BHARDWAJ** (109ME0035) for the partial fulfillment of the requirements **of Bachelor of Technology degree in Mechanical engineering** is a bona fide thesis work done by him under my supervision during the academic year 2012-2013, in the Department of Mechanical Engineering, National Institute of Technology Rourkela, India.

The results presented in this thesis have not been submitted elsewhere for the award of any other degree or diploma.

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CONTENTS

1. *ABSTRACT*

Since recent few decades natural fiber composites have been gaining more and more importance and attention over synthetic fibers on account of their various advantages and applications. An appropriate electrical application of natural fiber composites depends on the electrical conductivity of the composite known very well. Also electrical conductivity due to moisture absorption of natural fiber plastic composites is one major concern in their outdoor applications. Dry natural fiber composite has no measurable electrical conductivity. After absorbing moisture from atmosphere or any other means natural fibers impart electrical conductivity to composites which is undesirable even though it is very low. This conductivity increases with the amount of fiber loading and not depends on the orientation of fiber in matrix. A proper setup is made to measure electrical conductivity of natural fiber composite sample at different fiber loading which gives the conductivity values in close proximity to the earlier made approaches to find electrical conductivities with different samples and compare the values obtained to get a graph showing that after percolation threshold value the conductivity of natural fiber composite increases with increase in fiber loading.

2. INTRODUCTION

I. COMPOSITE

Composites can be defined as combinations of two materials one of which is called the reinforcing phase which can be in the form of fiber sheets or particles and are embedded in the other material called the matrix phase. The objective is to take benefit of the superior properties of both the materials without compromising on the weakness of either. Mechanical properties of composites depend on the size, shape and volume fraction of the reinforcement, reaction at the interface matrix material. The composites are compound materials which differ from alloys by the fact that the individual components retain their characteristics but are so incorporated into the composite as to take advantage only of their attributes and not of their short comings, in order to obtain improved materials [4]. There are two categories of constituent materials of composite materials: matrix and reinforcement. The matrix material supports and surrounds the reinforcement materials and simultaneously maintains there relative position. The reinforcements impart their special mechanical and physical properties to enhance the matrix properties.

MATRIX PHASE

1. The primary phase, having a continuous character.

2. Usually more ductile and less hard phase.

3. Holds the reinforcing phase and shares a load with it.

REINFORCING PHASE

1. Second phase (or phases) is embedded in the matrix in a discontinuous form,

2. It is sometimes called reinforcement phase as it is usually stronger than matrix phase.

II. TYPES OF COMPOSITES:

Broadly composites are classified on the basis of the two main phases present in them that is matrix phase and reinforcing phase as follows:

On the basis of Matrix Phase:

1. Metal Matrix Composites (MMC)

Metal Matrix Composites are composed of a metallic matrix (aluminum, magnesium, iron, cobalt, copper) and a dispersed ceramic (oxides, carbides) or metallic (lead, tungsten, molybdenum) phase. Metal Matrix Composites have many advantages over monolithic metals like higher specific strength, higher specific modulus and better properties at higher temperatures, and at lower thermal expansion coefficient.

2. Ceramic Matrix Composites (CMC)

Ceramic Matrix Composites are composed of a ceramic matrix and reinforced with short fibers, or whiskers such as those made from silicon carbide and boron nitride. Ceramic fibers, such as alumina and SiC (Silicon Carbide) are advantageous in very high temperature applications, and also where there is a risk of environment attack.

3. Polymer Matrix Composites (PMC)

Polymer Matrix Composites are composed of a matrix from thermosetting (Unsaturated polyester (UP), Epoxy) or thermoplastic (PVC, Nylon, Polystyrene) and embedded glass, carbon, steel or Kevlar fibers (dispersed phase). Most commonly used matrix materials are polymeric. Processing of polymer matrix composites need not involve high pressure and doesn’t require high temperature. Also equipment required for manufacturing polymer matrix composites are simpler.

On the basis of reinforcing material:

a) Fiber Reinforced composite

Common fiber reinforced composites are composed of fibers and a matrix. The reinforcement phase consists of fiber and the main source of strength while matrix glues all the fibers together in shape and transfers stresses between the reinforcing fibers. The fibers carry the loads along their longitudinal directions. Common fiber reinforcing agents include carbon graphite fibers, asbestos, beryllium, beryllium oxide, molybdenum, aluminum oxide, bio fibers glass fibers, polyamide etc. Similarly generally used matrix materials include epoxy, polypropylene, phenolic resin, vinyl ester, polyester, polyurethane, etc. Polyester is most widely used among these resin materials.

b) Particle Reinforced composite

Particulate Composites consist of a matrix reinforced by a dispersed phase in form of Particles. Particles used for reinforcing include ceramics and glasses such as small metal particles such as aluminum and amorphous materials, mineral particles, including carbon black and polymers. By using particles modules of the matrix gets increased and ductility of the matrix gets reduced. Particles are also used to reduce the cost of the composites. An example of particle reinforced composites is an automobile tire, which has carbon black particles in a matrix of poly-isobutylene elastomeric polymer.

III. NATURAL FIBER COMPOSITE

Since recent past, environmental apprehension encourages the researchers from every part of the world on the studies of natural fiber composite and cost effective option to synthetic fiber reinforced composites. The ease of manufacturing and availability of natural fibers have tempted researchers to try locally available inexpensive natural fibers and to study their expediency of reinforcement purposes and to what extent they satisfy the required specifications of good reinforced polymer composite for different applications. With high specific mechanical properties and low cost, natural fiber represents a biodegradable and good renewable alternative to the most common synthetic reinforcement, i.e. glass fiber. Increased technical innovation, continuing political and environmental pressure, identification of new applications and government investments in new methods for fiber harvesting and processing are leading to projections of continued growth in the use of natural fibers in composites, with expectation of reaching 100,000 tons per annum by 2010 [10]. When the specific modulus of natural fibers is considered, the natural fibers show values that are comparable to or even better than glass fibers. Material cost savings, due to the use of natural fibers and high fiber filling levels, coupled with the advantage of being non-abrasive to the mixing and molding equipment make natural fibers an exciting prospect. These benefits mean natural fibers could be used in many applications, including automotive, building, household appliances, and other applications. Composites in which the matrix phase is some natural fiber while the reinforcement phase may be thermoplastic material or any other like epoxy, polypropylene etc. is called Natural Fiber Composite. Since last decade, polymer composites reinforced with natural fibers have become a topic of concern due to desirable properties and broader applications of natural fibers. Also, natural fibers are very cheap, abundantly available, and renewable. So the products based on natural fiber composite having reinforced phase as thermoplastic material are more economical to produce than the original thermoplastics [5]. The application of composite materials in engineering as dielectric is becoming increasingly important. Therefore, studies on the electrical properties of natural fiber reinforced thermoplastic composites are very important [6]. Natural fiber composite materials have gained importance and popularity due to their lightweight, high stiffness, strength, corrosion resistance, and lower impact on the environment. Because of their quality, durability and other advantages, they are used to make a large variety of floor mats, yarn, rope etc. Plants, such as jute, sisal, kenaf, pineapple, flax, cotton, hemp, ramie, bamboo, banana, etc., as well as wood, a source of lignocellulose fibers, are usually applied as the reinforcement of composites. Their renewability, availability, low density, and price as well as overall good mechanical properties make them an attractive ecological alternative to glass, carbon and synthetic fibers used for the manufacturing of composites. Some natural fiber composites are: Bast fibers (flax, hemp, jute, kenaf…)-wood core surrounded by stem containing cellulose filaments, Leaf fibers (sisal, banana, palm), Seed fibers (cotton, coconut coir). Generally, plant or vegetable fibers are used to reinforce polymer matrices of natural fiber composites and plant fibers are a renewable resource and have the ability to be recycled which gives an extra edge over synthetic fibers.

IV. ADVANTAGES

- Available in plenty
- Cheap
- Renewable
- Corrosion resistance
- Light-weight and Good strength

V. ELECTRICAL CONDUCTIVITY

As composites are also proving good substitute in electrical applications (micro-chips, part of transformers and circuit boards) whether be it as an insulator or as a conductor with some modifications in their preparation, it has become extremely essential to carry out research in the field of determining electrical conductivity of various natural fiber composites. Electrical conductivity of a sample gives an insight into the macroscopic properties of the material related to its ability to the extent to which it can conduct electricity or behave as an insulator. The application of natural fiber composite in a particular electrical system totally depends on how much is the capability of the natural fiber to pass current through it. Like composites having negligible conductivity can be used as an insulator in various electrical circuits while those having higher value of conductivity can be used at points where there is a requirement of a good conducting material together with having high strength.

Electrical conductivity can be understood as a measure of how well a material conducts electricity. It is the inverse of electrical resistivity which is the measure of property of material by virtue of which it opposes the flow of current through it. It is commonly represented by the Greek letter σ (sigma) or κ (kappa).

The resistivity of a sample is calculated using the relation:

$$\rho = R\frac{A}{\ell}, \qquad (1)$$

Where,

R is the electrical resistance of a uniform sample of the material (measured in ohm)

ℓ is the length of the piece of material (measured in meters, m)

A is the cross-sectional area of the specimen (measured in square meters, m^2).

So, conductivity is calculated using the relation:

$$\sigma = \frac{1}{\rho}. \qquad (2)$$

$$= L/(R \times A) \qquad (3)$$

Where,

L is the length of sample (meter)

R is the resistance (ohm, Ω); A is cross sectional area of the specimen (sq. meter)

SI unit of conductivity is Siemens per meter (S/m)

For this a proper setup should be made to perform the experiment on and get conductivity of the composite sample. The conductivity of a composite sample has two aspects: microscopic conductivity, which depends upon the doping level, conjugation length, chain length, etc. and macroscopic conductivity, which is determined by external factors such as the compactness of the samples [8]. Usually, the percolation theory is used to describe the nonlinear electrical conductivity of extrinsic conductive polymer composites. The conducting additive is included into polymers at levels that allow the composite to maintain its electrically insulating qualities, as well as at higher levels, which allow the composite to become electrically semi conductive. As the volume fraction of the conducting filler particles increases, the particles come into contact with one another, fiber clusters become larger to form the conduction paths through the composite. As the result there is a threshold composition at which fiber cluster first spans from one side of the lattice to opposite side called infinite cluster at which the conductivity increases by some orders of magnitude from the insulating range to values in the semi conductive or metallic range [3]. The fiber content at this point is called percolation threshold. Above this threshold value as the fiber content increases the conductivity of the sample also increases.

3. AIM OF THE PRESENT WORK

To design experimental setup for measuring electrical conductivity of natural fiber composite which is cost efficient over other readymade setups available and perform experiment with different fiber loading to plot its variation.

4. LITRATURE REVIEW

Litrature survey/review is carried out as a part of this project work to have an overview of the natural based composite and their electrical conductivity characteristics.

W. Jia et al. [2] analyzed electrical conductivity of composites based on epoxy resin with polyaniline-DBSA fillers. Due to their vast applications electrically conductive thermosetting composite materials containing metallic filers are widely used now a day. The composite material used was conductive filler PANI-DBSA in form of powder and paste in matrix polymer bisphenol, an epoxy resin, anhydride hardener and an accelerator. The variation of electrical resistivity which is the inverse of electrical conductivity was plotted with content of PANI-powder. With 40% wt. /wt. of filler content electrical conductivity of the order of 10^{-8} ohm-cm was observed which gradually increases or the resistivity gradually decreases as the wt. % of filler material increases. At higher filler content conductivity of the order 10^{-3} was also achievable in the experiment.

M.M. Pavlović et al. [3] studied electrical conductivity of lignocellulose composites loaded with electrodeposited copper powders at different pressures and compared the results with previous researches in this field and percolation theories. It stated that the electrical conductivity of the composites is < 10^{-15} MS/m, unless the metal content reaches the percolation threshold of 14.4% (v/v), beyond which the conductivity increases markedly. As lignocellulose based fibers have some interesting properties, they are widely used. The metal fibers alter the electrical properties of the composite keeping the mechanical properties unvaried. The electrically conducting polymer composites have several benefits over their pure metal counterparts, such as ease of manufacture, corrosion resistance, reduced weight, lower cost, high flexibility, and conductivity control and mechanical shock absorption ability, [7]. In order to have more contact between filler materials for better conduction copper in the form of powder was used as a filler material. It was observed that the samples with low filler content were nonconductive and increases as the filler amount increases. The significant increase in the electrical conductivity was observed as the copper content reached the percolation threshold at 14.4% (v/v) for all the processing pressures. As the surface to volume ratio of the filler material added was high the percolation threshold was much lower. Logarithmic value of electrical conductivity was plotted against percentage volume of filler content, of lignocellulose composites filled with copper powder under different processing pressures which showed typical S-shaped dependency with three distinct regions: dielectric, transition and conductive. The average value of conductivity obtained at percolation threshold value was obtained to be of the order 10^{-5} which increased to 10^{-2}-0.1 with increase in fiber loading to 30 %.

Gelfuso et al. [9] did research on Polypropylene Matrix Composites Reinforced with Coconut Fibers with the goal to combine low cost and eco-friendly treatments to improve fiber-matrix adhesion for which electrical resistivity (inverse of electrical conductivity) of prepared sample were also calculated. Coconut fiber-polypropylene composite boxes containing up to 20 vol. (%) of coir fibers were formed by injection molding. Square specimens of 50×50 mm dimensions and 3 mm thickness were put between copper plates, which were used as electrodes. An electric voltage of 5 kilo-Volt DC was applied to the samples to obtain the electrical resistance measurements, and lastly the electrical conductivity values were obtained using the conductivity formula: σ= (L/R*A). The conductivity of the sample was found to be of the order 10^{-7} Siemens/meter at 10 vol. (%) to 10^{-3} S/m at 20 vol. (%) of fiber loading.

D.S. Pramila Devi et al. [8] studied the electrical conductivity of elastomeric composites of polypyrrole (PPy) and PPy coated short Nylon-6 fiber (F-PPy) based on natural rubber (NR) prepared by in situ polymerization method. Polypyrrole (PPy) is a good conducting polymer and it can also be synthesized without much effort and so it has been used in various electrical applications like rechargeable batteries, electromagnetic shield, circuit boards etc. The composite is prepared and electrical conductivity of the composite’s sample (rectangular strips of dimensions 4 mm × 2 mm × 2 mm) were measured by a standard two-probe electrode configuration using a Keithley2400 source measure unit in dry air at ambient temperature. The sample was placed between two electrodes through which current was passed and the resistance was measured directly from the instrument. The conductivity of the samples was calculated using the formula: $\sigma(\text{S/cm})$ = (I/V) × (L/A), where r is the electrical conductivity, I is the magnitude of current passing through the electrode in amperes, V is the voltage in volts, l is the thickness of the sample in centimeters and A is the area of contact of the electrodes with the sample in centimeter square. And log of conductivity was plotted against the fiber loading of the composite which showed DC conductivity of NR/PPy composites is enhanced only at very high PPy loading and the maximum conductivity 8.3×10^{-4} S/cm is attained at 100 phr loading. Presence of PPy coated fibers in the NR/PPy system increases the conductivity substantially and the maximum conductivity attained is 6.25×10^{-2} S/ cm.

W. Wang et al. [1] carried out research to introduce percolation theory and its concepts while carrying out experiment to investigate moisture absorption and electrical conductivity in natural fiber plastic composites using the concepts. According to her, initially the dry NFPC has no measurable electrical conductivity. After water submersion, at the fiber content at which fiber cluster first spans from one side of the lattice to other side called percolation threshold, natural fibers belonging to an infinite cluster absorb moisture and thus impart electrical conductivity to composites even though it is very low. This conductivity depends more on the number of conduction passages rather than the ratio of fibers belonging to the infinite 3D-network as depicted in fig. below:

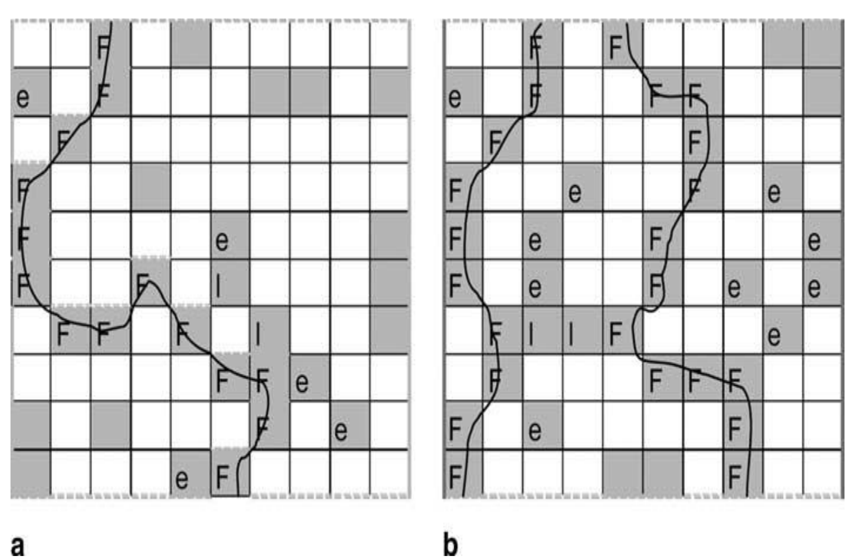


Fig. Flow passages in lattice with different fiber contents: (a) with one flow passage; (b) with two flow passages

Within this infinite cluster, two types of fibers are differentiated to facilitate the discussion of conductivity. As shown in Fig. fibers marked with ‘‘e’’ are the dangling ends of infinite cluster; they absorb moisture but do not serve as moisture passages and so do not contribute to the conductivity of the lattice. Fibers marked with ‘‘l’’ form loops inside the infinite cluster and also do not increase the conductivity of the lattice. ‘‘F’’ represents fibers which form continuous passages for moisture and thus contribute to the conductivity of the lattice. Composite of rice hulls in HDPE was prepared with five sheets of different rice hull loadings, i.e., 40%, 50%, 55%, 60%, 65% by weight and sample of dimension 2×2×2.4 cm dimension was cut out from each. After moisture absorption and drying under proper electrical arrangement electrical conductance of the samples were calculated. A graph of conductance against the square root of time for which sample remains in moisture is plotted for different fiber loaded samples. It shows negligible conductivity values at low fiber loading while observable at higher loading that is due to the fact that plastics do encapsulate the natural fibers and prevent the moisture of composites at low fiber loading through conduction occurs.

5. MATERIALS AND METHODOLOGY

I. MATERIALS

A natural fiber plastic composite with rice husk (natural fiber) as reinforcement phase in epoxy as matrix phase is prepared. Four samples with different percentage by weight of rice husk loading is prepared i.e 40%, 50%, 60%, 70% by weight to measure and compare the electrical conductivities of different samples. The important properties of Rice husk is that, it is a fibrous material and has a varied range of aspect ratio (length to diameter ratio of fiber). Its composition makes it potential filler for making lightweight polymer composites.

Samples of dimension 2cm×2cm×0.4 cm is cut out from each composite sheet. As from the literature review we come to know that for natural fiber composite to conduct electricity it has to absorb moisture as dry natural fiber composite has no measurable conductivity, Samples were immersed in distilled water at room temperature, i.e., 23 ^{0}C. After specific time intervals, samples were removed from water, their surface moisture was removed by tissue paper, and their electrical conductivities were measured immediately which is discussed in section 4.II.

II. EXPERIMENTAL PROCEDURE

The electrical resistance of the sample was very high and so conductivity very less which was not measurable when dry. But after moisture absorption it showed electric current passing through on the digital multimeter. For measuring electrical conductivity of the composite sample, a proper electrical set-up is established as shown in figure 2 and figure 3.

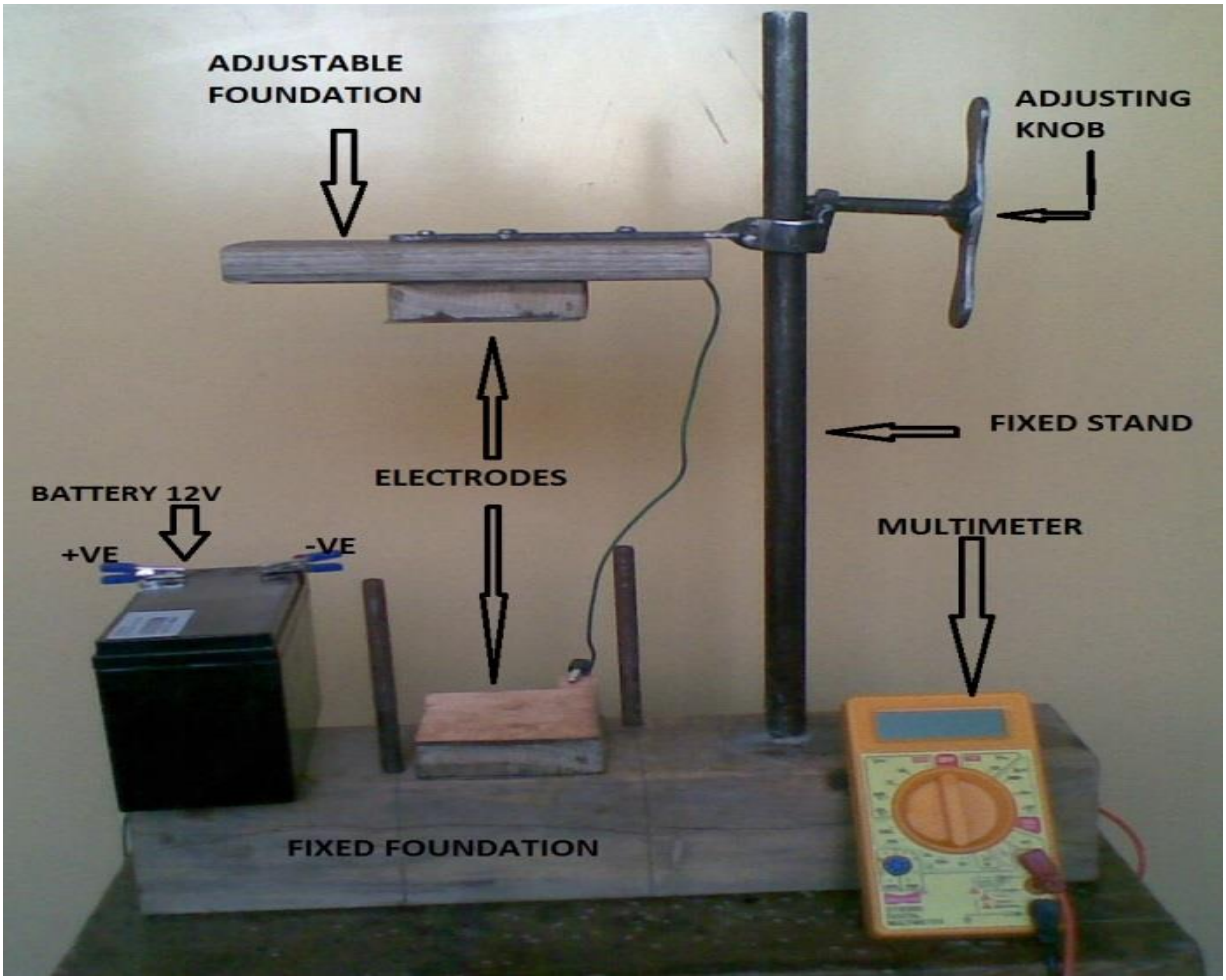


Fig. 2. Experimental set-up of electrical current measurement (without sample)

The above figure is the experimental set-up made for measuring electric current flowing through the composite from which resistance and hence conductivity is calculated. A 12 Volt battery is the source of power to the circuit. Fixed single side conducting copper plates acts as electrode plate. One of the plates is fixed to the fixed foundation while the other plate is fixed on the adjustable foundation whose height can be adjusted while removing and placing the composite sample on the electrode attached to fixed foundation. The adjustable foundation can me moved down using adjusting knob and tightened using the two bolts with the fixed foundation. One terminal of battery is directly connected to the plate over adjustable foundation which is negative terminal and so the fixed foundation plate is cathode. The other terminal of the battery is goes through the digital multimeter which connected in series with the circuit for current measurement. First the fixed resistance of the circuit is calculated by short-circuiting the circuit and then the composite sample is placed on the fixed foundation and the adjustable foundation is bought down and then tightened with sufficient pressure using the bolts as shown in fig. 3 below and the current reading is noted down on the digital multimeter.

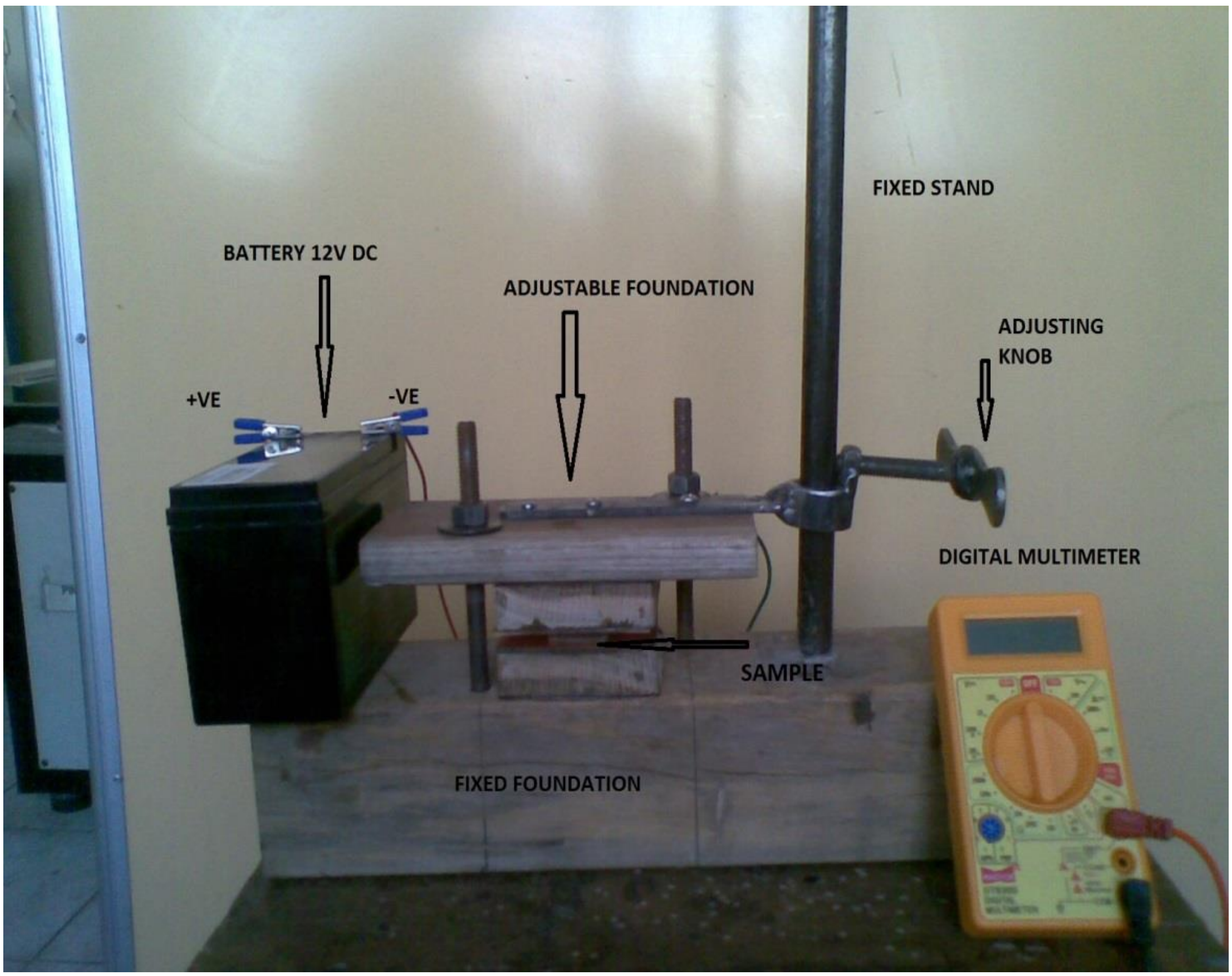


Fig. 3. Experimental set-up of electrical current measurement (with sample)

The fixed circuit resistance of the circuit is obtained as: $R_0 = (V/ I)$ (4)

Where,

V is short-circuit voltage i.e 12V, I is short circuit current as shown on multimeter = 0.667 amp

So, $R_o = 18$ V

And then the resistance of the circuit is given as:

$$\mathbf{R = [(V \div I) - R_o]} \qquad (5)$$

And finally Electrical conductivity is given by equation:

$$\sigma = \mathbf{[\, L \div (R \times A)\,]} \qquad (6)$$

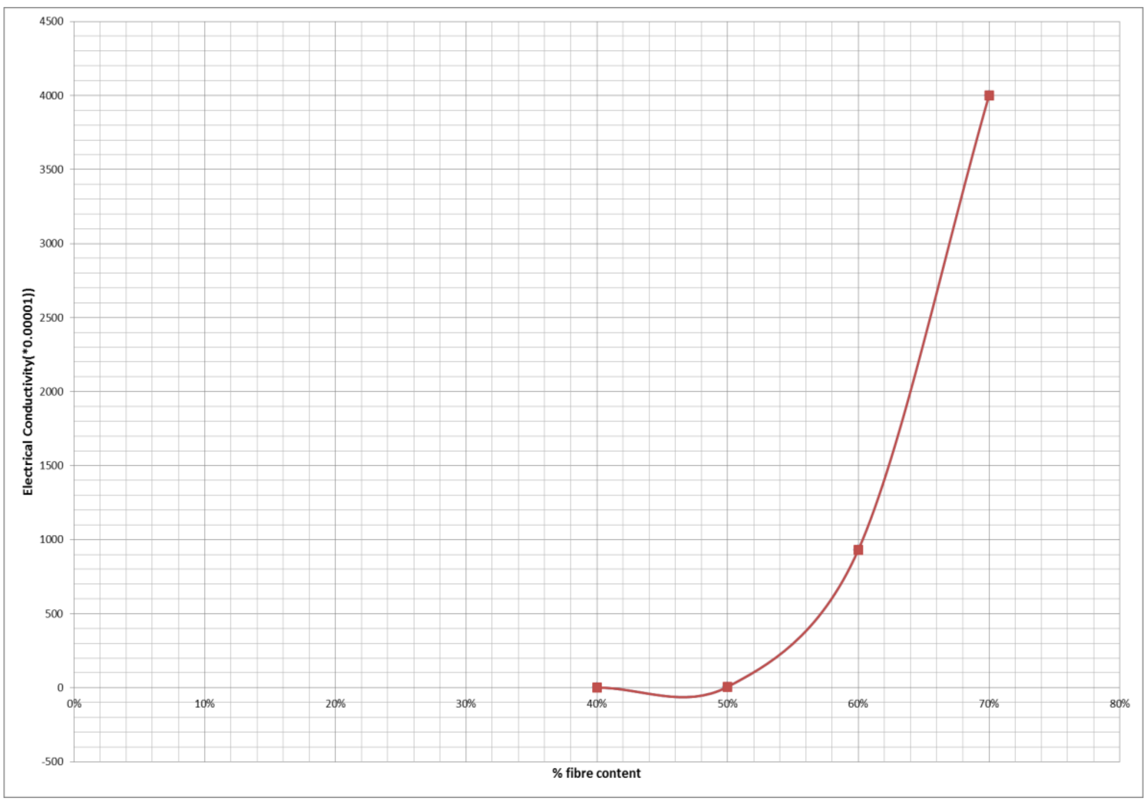
Where,

L= length of sample =0.4cm = 0.004m

A= area of cross section of sample in contact with electrode = 2*2= $4cm^2$= 4×10^{-4} m^2

6. RESULT AND DISCUSSION

For the sample with 40% (wt. /wt.) of the fiber, the digital multimeter showed the reading 0.0132 ampere of current through the sample. From this, resistance was calculated by the formula in equation (5) that was found to be 909 kilo-ohms which can be approximated as of the order 10^6. Then using equation (6) the conductivity of the sample was found to be 1.1×10^{-5} ohm-meter (Ω-m). Similarly for other samples also conductivity was obtained and a graph is plotted as shown:



Electrical conductivity × 10^{-5} Ω-m on Y axis v/s percentage fiber content on the X-axis.

7. CONCLUSION

From the experimental investigation and study it is concluded that

- The experimental set-up is working good as it gives conductivity values in close proximity to the earlier obtained values in different researches. This setup is far cheaper than the ready-made machines used to measure electrical properties of the composite.

- The electrical conductivity increases as the natural fiber content in the fiber increases beyond percolation threshold value.

- The equipment can be further modified by using other materials like steel or iron in place of wood to make adjustable fixtures and fixed foundations which could not be done due to time constraint. It can also be used for measuring electrical conductivities of composites other than natural fiber composites with slight modifications in arrangement if required.

8. REFERENCES

[1] Wang W, Sain M, Cooper P.A: "Study of moisture absorption in natural fiber plastic composites", composites Science and Technology 66 (2006) 379–386

[2] Jia W, Tchoudakov R, Segal E, Joseph R, Narkis M, Siegman A: "Electrically conductive composites based on epoxy resin with polyaniline-DBSA fillers", synthetic metals 132 (2003) 269-278

[3] Pavlović M.M, Cosovic V, Pavlović M.G, Talijan N, Bojanić V: "Electrical Conductivity of Lignocellulose Composites Loaded with Electrodeposited Copper Powders" Int. J. Electrochem. Sci., 6 (2011) 3812 - 3829

[4] Berghezan, Nucleus A, 8(5), 1966,(Nucleus A Editeur,1,rhe,Chalgrin,Paris, 16(e).

[5] Maldas D, Kokta B.V, Raj R.G, and Danealut c, Polymer, 29, 1255 (1988).

[6] Paul Augustine and Thomasz samu, Journal of Applied Polymer Science, Vol. 63, 247-266 (1997)

[7] Poblete V.H, lvarez M.P.A and Fuenzalida V.M, Polymer Composites, 30 (2009) 328.

[8] Pramila Devi D.S, Bipinbal P.K, Jabin T, Kutty Sunil K.N : "Enhanced electrical conductivity of polypyrrole/polypyrrole coated short nylon fiber/natural rubber composites prepared by in situ polymerization in latex", Materials and Design 43 (2013) 337–347

[9] Gelfusoa Maria Virginia, Pedro Vieira Gurgel da Silvab, Thomazinia Daniel: "Polypropylene Matrix Composites Reinforced with Coconut Fibers", Materials Research. 2011; 14(3): 360-365.

[10] Clemons, Craig M., Caulfield, Daniel F., 2005, "Natural Fibers, Functional fillers for plastics," Weinheim: Wiley-VCH: pp.195-206.