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Electrical Insulating Properties of Natural Fibre Reinforced Polymer Composites; A Review

Mr. Narayan Nayak[1], Dr. Reddappa H. N[2], Mr. Ganesh Kalagi[3], Mr. Vijendra Bhat[4]
[1] Department of Mechanical Engineering SMVITM, Bantakal, Udupi, India.
[2] Department of Mechanical Engineering BIT, Bengaluru, India.
[3] Department of Mechanical Engineering SMVITM, Bantakal, Udupi, India
[3] Department of Mechanical Engineering SMVITM, Bantakal, Udupi, India

***Abstract*—Natural fiber-reinforced polymer composites have raised great attention and interest among materials scientists and engineers in recent years. Composites give a combination of superior mechanical property, dielectric property, and environmental advantages such as renewability and biodegradability. Composite Materials are ideal for electrical and electronic applications because of their high Dielectric strength and Arc Resistance properties.**

Keywords*— *Composites, Natural Fibres, Dielectric Constant

I. INTRODUCTION

Composite materials due its strength to weight ratio grabbed attention from material engineers and scientists. Natural fiber reinforced thermoplastic material have great advantages in non-critical applications. Natural fibers that have been evaluated as replacements for glass and other non-recyclable fibers. Natural plant fibers are renewable non-abrasive and reduce health and safety concerns while handling. In addition, they show excellent specific mechanical properties, low cost, low density and enhanced energy recovery compared to traditional glass and carbon fibers.

Not only in mechanical engineering applications composites can also be used for electrical applications also like as insulator for wires, for shielding the cables etc. Where mechanical and electrical properties of composite play very important role. With fillers in the form of fibers and flakes have been found to be most effective for this purpose due to the lower volume fractions needed to achieve a targeted conductivity. [1-5]

PLASTICS

Plastics are nothing but polymers formed due the molecular reaction of monomers. Depending upon their chemistry they can be very much like rubber, or as strong as aluminum. Most plastic materials are excellent insulators, both electrical and thermal. On the other hand, plastic composites can be made to be electrically conductive with the addition of carbon or metal fibers. In general, the combination of light weight, high strength, and low processing costs make thermoplastics well suited to many applications. Generally, two types of plastic materials are there thermoplastics and thermosettings.

Thermosettings

The polymers which undergo chemical changes and cross likings on heating and become permanently hard, rigid and infusible are called thermosetting. Examples: Phenol formaldehyde resins, Urea formaldehyde resin, epoxy resin etc.

Thermoplastics

A thermoplastic is a material which becomes soft when heated and hard when cooled. Thermoplastic materials can be cooled and heated several times. They can be recycled. When thermoplastics are heated, they melt to a liquid. Thermoplastics have wide ranging properties. Some of the thermoplastics have good mechanical and electrical properties which is listed below. Poly-ethylene, Poly-vinyl chloride, polypropylene, and polyester are some of the commonly used polymers in industries for wide range of applications.

Most of the thermoplastics have very low density around 1 when it is compared with Iron which has density of 7.8. Even maximum tensile strength of thermoplastic is found to be 62 MPa and hence its properties can be improved by reinforcing natural fibers. Thermoplastic materials are very good insulators. The electrical insulating strength is usually measured with the help of dielectric strength Which can be defined as the voltage gradient that produces electrical break-down through material. The dielectric strength of material is above 10000 V/mm. Thermoplastic materials having low operating temperature. It can be operated up to 150^{o} C.

So some of the plastics are used as insulator in different forms as mentioned below Insulators are in three different forms solid, semi-solid, and foams.

- Solids are easy to apply but density is more compared to semi solids and foams. Semi solids are 50% void materials dielectric strength of 1.6.
- Generally, semi solids are not used as jackets. Jackets are protective element that protect internal elements and improves the cable appearance. It protects the elements from environmental attack.
- So polyethylene, polypropylene, Poly Vinyl Chlorides, Rubbers etc., are used as insulating materials for wire cables till now and their properties are mentioned below. [20]

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Material	Density (g/cm^3)	Tensile strength (Mpa)	Impact Strength (J/m)	Dielectric strength (V/mm)	Max Temp(^oC)
Poly ethylene low density high density	 0.92-0.93 0.95-0.96	 6.2-17.2 20-37	 21-747	 18900 18900	 82-100 80-120
Rigid chlorinated PVC	1.49-1.58	52-62	54-299		110
Poly propylene	0.90-0.91	33-38	21-117	25600	107-150

Fibers

Fibers are a class of hair-like materials that are continuous "'filaments"' or are in discrete elongated pieces, similar to pieces of thread. Fibers are used as a reinforcement material to strengthen the matrix material. The shape of the fiber is almost cylindrical. Natural fibers are available in nature which can be derived from plants or animals. And hence renewable, cheaper, pose no health hazards. After suitable treatment it shows good mechanical strength. Natural fibers are greatly elongated substances that can be spun into filaments, thread or rope, woven, knitted, matted or bonded, they form fabrics that are essential to society. Coir, Cotton, Hemp, sisal, kenaf, Jute and flax are commonly used natural fibers. But when compared with glass fibers moisture absorption is a major problem. To avoid this, it can be suitably treated with acid or base solution. [10,11]

Table 2. Mechanical properties of natural fibers

Fibre	Density (g/cm^3)	Tensile strength MPa
Flax	1.54	345-2000
Jute	1.44	393-773
Sisal	1.45-1.5	350-700
Kenaf	1.2	240-930

Natural fibers have almost density around 1.5 g/cm^3. But having good mechanical strength up to 3000 MPa. Mechanical properties of the few natural fibers are listed below

Since natural fibers have better strength compared to thermoplastics. Natural fibers can be successfully reinforced in thermoplastics which gives better mechanical properties. But due to poor bonding property of the thermoplastics de-bonding and fiber pull-out becomes major problem. And moisture absorption is also one of the major concern because it increases the dielectric constant and spoils the insulating property. So fiber treatment becomes very important. Different types of treatments are washing with chemicals, heat-treatment, hybridizations etc. [12]

The uses of natural fiber reinforced composites as dielectric are becoming more popular, because of its electrical insulating properties. Nowadays, many rubber and plastic compounds have been used in antistatic applications such as wire and cable sheathing shielding against electromagnetic interference, etc. Electrical properties mean insulating properties not conducting properties like dielectric strength, dielectric constant, dissipation factors etc. [14]

II. NATURAL FIBRE REINFORCED POLYMER ELECTRICAL PROPERTIRES

Different properties are required for making wires and cables, in that electrical and mechanical properties are very important Some of the electrical properties like Dielectric strength, Dielectric constant are important. Dielectric strength means ability to withstand voltage without breakdown. Air is best dielectric material with dielectric constant of one. Adding the foam material lowers the dielectric strength of the material. Physical and mechanical properties of electrical wires and cables are also important factors. Physical means, temperature rating, specific gravity etc. Mechanical means elongation, tensile strength, flexibility etc. Flexibility means bending property how easily wire can be bend. Good flexibility means it can be rolled or coiled easily without any physical damage. Temperature rating means the range of temperature within that material can be used without degradation. Wide temperature range is always better. Flammability means the temperature at which wire catches fire (industrial standards are applied). Specific gravity means density compared to water. It depends upon the density of material and hence lower density materials are always preferred. How much material can be stretched without breaking is the elongation its always expressed with percentage elongation.

So some of the properties are discussed with some experimental results.

The dielectric property of material is important factor for electrical applications. The dielectric constant of composite mainly depends upon the dipole interaction present and orientation effect.

The dielectric constant of non-polar polymer lies between 1.8-2.6. The dielectric constant of vacuum is one and infinity for conductor. And for the rest of insulator it should be greater than one. Lesser the value of dielectric constant, insulator will be more efficient. But due to moisture absorption conductivity of fiber increases and hence dielectric constant of fiber increases and its insulating property decreases. So fibers are usually treated with chemicals. [13-15]

Natural fibers contain numerous hydroxyl groups. So Interacts with water molecules by hydrogen bonding. Natural fiber also contains small voids, cracks, under moist condition theses spaces are filled with water. So, Natural fiber reinforced polymers can take up high amounts of water, which generally causes a reduction in mechanical properties. By treating the natural fibers with alkaline solution or by

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using coupling agents' moisture absorption problem can be minimized. When fibers are treated with alkaline or acidic solution it prevents the establishment of hydroxyl groups on the filler surface and functional groups. When fibers are heat treated it dries out the moisture content. [17]

It has been observed that dielectric constant increased with increase of temperature and decreased with increase of frequency. This increase in dielectric constant was due to presence of water and impurities present in fiber and also due to mobility of water dipole.

The dielectric constant of material depends upon the polarizability of the material. If there is greater polarizability of molecule, dielectric constant will be high. It has been observed that dielectric loss factor decreased with the increase of frequency at fixed temperature. [3].

Seena Joseph et al [1] studied electrical properties of banana fiber reinforced phenol formaldehyde composites with fiber loading, fiber treatments and hybridization with glass fibers. Treatments with silanes, NaOH and acetylation, latex treatment and heat treatment, decreased the dielectric constant value.

It has been observed that dielectric constant increased with increase of temperature and decreased with increase of frequency. When the water content reduced then the value of dielectric constant decreased. The peak height at the transition temperature decreased with increasing frequency. The change in the fiber loading or treatment changes the structure and hence dielectric constant. [1,9]

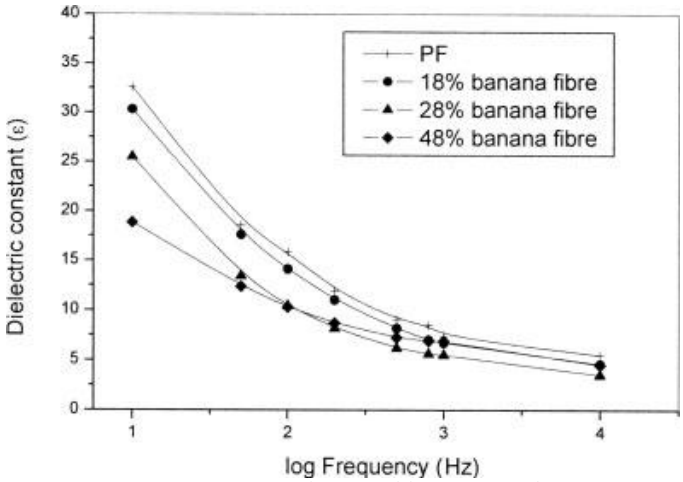

Figure 1 Dielectric constant as function of frequency and fiber loading

The resistivity of fiber reinforced composites depend on the moisture content, crystalline and amorphous component present, presence of impurities, chemical composition, cellular structure. The shapes of reinforcement determine the inter particle contact, which affect the conductivity of the system. Fibers and flakes having elongated shapes affect the electrical conductivity.

To make wires, flexibility is also one of the important criteria. The whole length of wire can be stored in small space by using flexibility property. But when natural fiber polymer composites are manufactured hardeners are generally used. When hardeners are used composites become brittle and cannot be moulded with the help of injection moulding. But if the same brittle composites show good electrical properties along with the mechanical properties they can be used as switch boards and other electrical boards.

Melissa Gurgel et al [7] To improve the flexibility of the polymers plasticiser are used which changes the internal property of polymers without much appreciable change in the mechanical properties. Plasticisers are a rather special type of additives. Without plasticisers most injection molding compounds would be entirely unsuitable for that purpose, and without plasticisers, some blends of rubber simply could not be produced. Injection molding is a widely used technique for mass producing articles with a high degree of geometrical complexity. Injection molding has many advantages, such as short product cycle, excellent surface of the product and easily molded complicated shapes Generally, camphor, vegetable-oils are used as plasticisers. "Plastic" always consists of very long chain molecules that under extremely high magnification would look like long threads. A plastic in which these threads are loosely tangled together is flexible. In the case of many plastics, however, these threads have a tendency to lie on top of one another like packed spaghetti.

Mustafizur Rahman et al [8] A similar thing happens in the case of the chain molecules of plastics. A rigid structure that is similar to the strictly regular composition of crystals allows the plastic to appear rigid on the outside. In the pan as well as in the test tube, the rule is: loosely tangled is flexible, rigid structure is hard. This is where the plasticisers come in. What it comes down to in the majority of cases, irrespective of whether it may camphor or mineral oil, is molecules that are very much smaller than the chain molecules of the polymer material and that are interwoven into their spaghetti like structure as the plastic is processed. They then push their way between the adjacent threads of plastic molecules, setting them apart from one another, and act rather in the same way as oil does on a plate of spaghetti, in that it allows the strands of pasta to slide past one another. This means that a loose, freely mobile structure can be created the plastic becomes flexible and that the more plasticiser is added, the more flexible it becomes.

Dielectric loss factor measure of loss of energy in a dielectric material through conduction, slow polarization of currents and other dissipative phenomena. Seena Joseph et al [1] In banana fiber composites, at low frequencies as the fiber loading increases, the loss factor also increases. But at high frequencies a reverse behavior is observed and the values come closer. This is due to polarization of the fibers at low frequencies, which is absent at higher frequencies. All types of treatments except the NaOH treatment decrease the loss factor.

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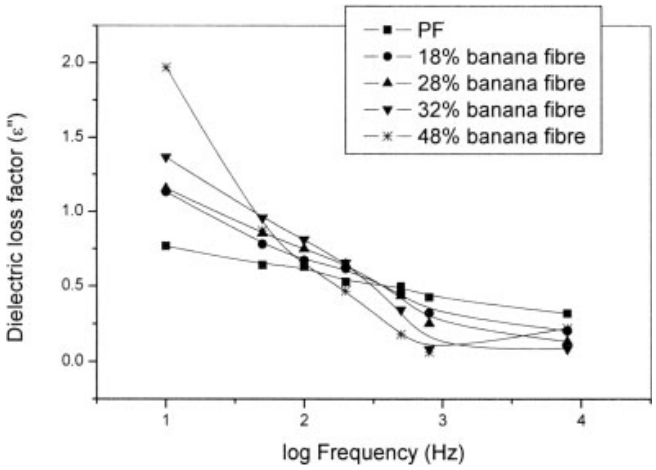

Figure 2 Variation of Dielectric loss factor with fiber loading

P.A. Sreekumar et al [4] The electrical loss or the amount of energy dissipated by the insulating material when the voltage is applied to the circuit can be represented by means of a dissipation factor. Dissipation factor (tan δ) is the ratio of the electrical power dissipated in a material to the total power circulating in the circuit. The measurement of tan δ of an insulating material is important since the loss tangent is a measure of the electrical energy, which is converted to heat in an insulator. This heat raises the insulator temperature and accelerates its deterioration. The average power factor over a given period of time, is expressed as (έ), the loss factor. The loss factor (έ), is used in the energy industry to express the losses in distribution and transmission.

Elammaran Jayamania et al [2] The dissipation factor was found to decrease with an increase in the frequency. When the fiber loading was increased, in the low frequency region, it showed a significant variation behavior of the result that was lowest for pure matrix material and highest for high fiber loading at a given frequency.

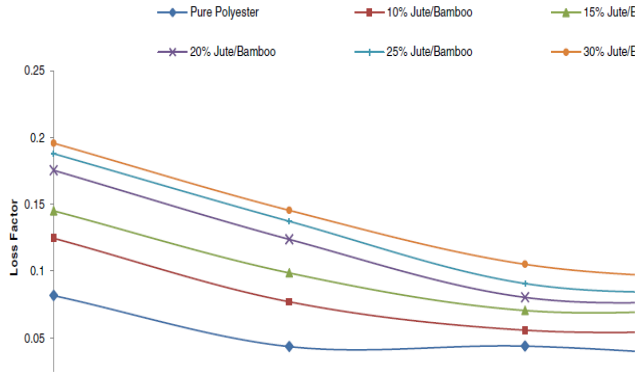

Figure 3 Effect of fiber loading on dissipation factor

From the above study, when volume of fiber is more then it reduces the dissipation factor and reduces the dielectric constant which is very much required. But Ana Espert et al [16] studied relation between water absorption and mechanical strength of composites; Due to the moisture absorption mechanical strength of the fiber decreases. And moisture absorbed by the thermoplastics are very less and hence it has no effect on the mechanical properties of composites. When volume of the fiber(fiber-loading) increase moisture absorption also increases which can be minimized by treating the fibers.

Whenever current flows through conductor it produces heat So composite should have good thermal stability. It is also called as temperature rating of composites. Polymers can withstand up to 150-200^0 C. Ryszard Kozlowski et al [18] reviewed that natural fibers can withstand up to 300^0 C temperature. However, its thermal degradation increases in the presence of heat stimuli, when oxygen concentration is more etc. Natural fiber consists of celluloses, hemicelluloses, and lignin as do wood. Thus it is as highly flammable as wood and hence its content portion will affect the flammability of composites. The thermal degradation of kenaf fiber starts at 350^{0}C. And the thermal degradation of the fiber also depends upon the matrix phase also. For example, polypropylene matrix has good resistant to thermal degradation compared to other kind of thermoplastics and thermosettings. By the application of retardant like boric acid, ammonium phosphate on the natural fibers its temperature rating can be increased. The best way of increasing temperature rating of composites is by using non-flammable matrix. Even moisture present in the fiber reduces the flammability but affects the other mechanical and electrical properties of composites.

Most of the polymers are having density less than one gram per cubic centimeter. But natural fibers are having density more than one around 1.5g/cm^3. So reinforcing natural fibers in to polymer it increases the density of the polymer. But natural fibers are having very good tensile strength compared polymers. So reinforcing natural fibers gives better strength compared to its density.

Matko Sz et al [19] Waste accumulation problem can be minimized by the use of green-composites. Green composites are nothing but biodegradable composites they can be effectively utilized by the composting. By using various starch and cellulose material bio-composites can be prepared. Bio-composites have certain advantages like low- cost low density, biodegradability but it has several disadvantages like low thermal resistance, fiber swelling, low compressive and transverse strength etc. If these bio-composites fibers are treated with retardant(boric-acid) its thermal-resistance also increases and also minimizes the environmental effects.

III. CONCLUSIONS

From the experimental details of previous studies following things can be concluded

The regular plastic material which was used for making electrical insulators are less dense compared to the natural fiber, so by reinforcing natural fiber, density of the material increases with considerable increase in strength. Without the use of plasticizer composites become brittle and loses its flexibility. But whenever plasticizer is used it slightly lowers the tensile strength of the composite material. Fiber loading and fiber treatment alters not only mechanical but electrical properties like dielectric constant and dissipation factors. With higher fiber loading dielectric constant of the fiber decreases, but due to moisture absorption dielectric constant

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increases. Along with it its tensile strength decreases. Moisture absorption can be reduced by fiber treatments. Natural fiber reinforced composites can be used not only in mechanical engineering applications but also in electrical applications with certain modifications. Environmental effect can be minimized by the use of bio-composites. But bio-based polymers seem to be more expensive than the traditional mass polymers, their flame resistance can be achieved in relatively simple and inexpensive ways.

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