ELECTRICAL PROPERTIES OF ALKALI TREATED ACACIA AND CACTUS FIBER REINFORCED HYBRID POLYESTER COMPOSITES

K SAKTHIVADIVEL, P GOVINDASAMY
Department of Mechanical Engineering, Builders Engineering College, Tirupur, Tamil Nadu, India
ksakthivadivel@gmail.com
Department of Production Engineering, Dr. Mahalingam College of Engineering and Technology, India

Abstract: *The dielectric properties of alkali in the treated and untreated Acacia and Cactus fiber reinforced hybrid unsaturated polyester composites which are fabricated using hand layup technique are studied in different frequencies (3, 4, 5 and 6 Hz). The dielectric constant, dissipation factor and loss factor decrease with increase in log frequency. The depreciation in above mentioned property was high in alkali treated (Sodium Hydroxide) fiber composite as the impurities were removed on fiber surface as well as reduction in moisture absorption and interfacial bonding between the fiber and matrix were improved. The dielectric constant of hybrid composite decreased compared to other composites. The electrical conductivity was measured at room temperature which increased with an increase in the frequencies. As the electrical conductivity is low in these fiber composites, it can be suggested to use as insulation material in industries. Finally, the comparative study of dielectric properties for the treated and untreated Acacia and Cactus fiber composite and its hybrid composite were experimented.*

Key words: *Dielectric properties, Hand layup technique, Hybrid composite, Frequency.*

1. Introduction.

Now a days, our global market mainly focuses on the methods of energy conservation and less energy process. Generally, the composite fibers were frequently used in all areas where we are in need of less weight components. The natural fiber shows plenty of advantages when compared with the synthetic fiber in the aspects of renewable, biodegradability, cost and so on. Many researches were done in the area of natural fibers which is extracted naturally. The natural fibers are collected from naturally available plants by degradation process.

In the last few decades the natural plant fiber reinforced polymer composite are widely used in all the industries in macro and micro forms. Coir, banana, falx, oil palm, hemp, kenaf, jute, sisal, snake grass, etc., are widely used as reinforcement for the preparation of composites components [1-6]. Natural fibers are bio-based fibers obtained from plant/vegetable, animals and minerals which are alternative to synthetic fibers due to their low cost and comparable properties besides its composites are widely used in automotive industries [7].The natural plant fibers have many advantages though there are a few limitations which are to be studied. The major limitation of natural plant fibers is its hydrophilic nature which restricts the use of the fibers as reinforcement in polymer matrix composites. The inappropriateness between the hydrophilic fibers and hydrophobic matrix results in bulge due to moisture absorption and its shows the poor interfacial bonding between matrix and the fibers [8,9].

Improvement in the interfacial bonding between the fiber and matrix is due to the chemical treatments of fibers which reduce the hydrophilicity, fiber surface cleanness, reduce the moisture absorption process and improve the surface roughness [10,11]. A study shows that the influence of the alkaline treatment on Kenaf/polypropylene composites improves the mechanical and physical properties. Moreover they compared the alkaline treated fiber with non-alkaline treated fiber. Different fiber loadings of 10,20,30,40 50 wt% treated and untreated Kenaf fibers were fabricated. Through the experiments, they concluded that 40% of Kenaf/Polypropylene fiber composites show superior physical and mechanical properties than other fiber loadings [12].

The electrically conductive polymeric composites are rising now a days. The composite materials are successfully applied in electrical field so it is essential to evaluate about the factor like dielectric constant, dissipation factor and loss factor. The above properties depend on the chemical and physical structure of the materials [13]. Electrical properties of fiber reinforced polymer composites were studied numerously and reported [14-16]. Evaluation of the dielectric constant, loss factor and conductivity of the banana fiber reinforced polymer composite for different fiber loading showed the chemically treated fibers reinforced composite were found to be better in electrical conductivity than others [17].

The natural fiber polymer matrix composite materials are used in common applications like terminals, industrial and house hold plugs, connectors, switches, printed circuit boards, insulator, panels, etc[18]. Dielectric properties of short jute fiber reinforced polypropylene composites dependent on the fiber loading. And also when different fabrication techniques such as internal mixer, injection moulding, extrusion, etc., are done dielectric properties of the fiber composites will vary accordingly [19]. In the previous research it is concluded that electrical conductivity increased in the sisal-oil palm natural fiber reinforced hybrid rubber composite compared to sisal and oil palm fiber composites [20].

The dielectric properties of banana fiber phenol formaldehyde composite prepared by hand layup technique may increase or decrease on randomly oriented fiber mats with uniform thickness and different fiber loading. The dielectric constant value decreases in chemically treated (NaOH, acetylation, latex and cyanoethylation) fiber composites. The dielectric constant increases in banana fiber composite than glass fiber composite. The dielectric constant decreased in banana-glass fiber hybrid composite with increase in glass fiber concentration [21].

The dielectric properties such as dielectric constant, dissipation factor and loss factor are investigated for sisal fiber reinforced with poly-lactic acid matrix composite with different fiber loading and alkali treatment. When the fiber content increases the electrical properties increase at the same time when frequency increases, the electrical properties decrease. The dielectric constants of alkali treated fiber composites were lesser than the untreated fiber composites [22]. Sisal fiber reinforced polymer composites are prepared by resin transfer molding method. The dielectric, loss factor, dissipation factor and electrical conductivity are measured by varying the frequency and fiber content. The electrical properties increased in the 50% fiber content than others. This increment is very low at high frequencies and increased at low frequencies.

The dielectric properties are associated with experimental value with theoretical calculation [23]. The dielectric constant, loss factor and conductivity are analyzed for jute fiber Polypropylene composites where the electrical properties increased with increase in fiber content. Due to the chemical treatment of fiber the hydrophilic was reduced and the dielectric constant and electrical conductivity was decreased than untreated fiber composites. As the temperature increases the electrical properties, increase to a certain level whereas particular temperature electrical properties maintain a range [24].

The dielectric and mechanical properties of coir fiber polypropylene composites are prepared by compression molding technique. For improving the fiber-matrix interfacial bonding the chemical treatment is essential. The various chemical treatments are used for fiber surface enhancement such as alkali, acetone, stearic acid and potassium permanganate. The dielectric properties of the coir fiber composite are approximately same in all the chemical treatments. The dielectric constant is 2.56 for 25% chemically treated fiber content which is better than the untreated fiber composites. Finally the fiber content increased the dielectric properties values also increased rapidly [25]. Jute and bamboo fiber reinforced with unsaturated polyester and polypropylene composite are prepared with different fiber loading and chemical treatments.

The dielectric constant, loss factor and dissipation factor were studied and comparison of Jute and bamboo fiber composite and their hybrid composite were done. The dielectric constant increased with increase in fiber loading. The alkaline treated fiber composites observed lesser dielectric constant compared to others [26]. Grewia optiva fiber reinforced polymer composites are prepared and analyzed the mechanical, thermal and electrical properties. After fiber surface modification the dielectric constant, loss factor and dissipation factor improved than other composites [27].

In the present research work, the Acacia and Cactus natural fibers are used as reinforcement and unsaturated polyester resin as matrix are used for preparing the composites and investigated the electrical properties such as dielectric constant, dissipation factor, loss factor and electrical conductivity at different frequencies.

2. Experimental.

2.1 Materials

The Acacia fibers were extracted from the bark of Acacia Arabica Fabaceae tree by degradation process. Cactus fibers were extracted from the stems of Pencil Cactus tree (Euphorbia Tirucalli) by the same degradation process. The unsaturated polyester resin is used as matrix for preparing the composite laminate. The resin was mixed with catalysts and accelerator at a concentration of 0.01 w/w to cure rapidly. The typical properties of the unsaturated polyester resins are shown in Table 1.

Table 1

Typical properties of the unsaturated Polyester Resin

Appearance	Yellow Viscous liquid
Viscosity at 25˚C	200-300 cps
Specific Gravity at 25˚C	1.11±0.02
Acid value	25±5 mg KOH/g
Volatile Constant	40±2 wt%
Flexural Strength	25±2.5 MPa
Tensile Strength	18±1.5 MPa

2.2. Chemical Treatments

The Acacia and Cactus fibers were kept under the chemical treatment. The fibers were treated with 6% NaOH solution for 24 hrs with refined water. Then, the treated fibers were washed with running water to remove the impurities and dried in room temperature. The surface modification processes are made for improving surface roughness of fibers and remove the hydrophilic chemical composition. In addition to that hydroxyl groups are exposed which helped to improve the fiber/matrix bonding [28].

2.3. Preparation of Composites specimens

In this research, hand layup technique was used to prepare unsaturated polyester reinforced with Acacia and Cactus fiber composites and Acacia/Cactus hybrid fiber composites with random orientation where the treated and untreated fibers were fabricated by 25%

weight fraction and 30mm length of fibers. The composite specimens are prepared by mild steel disc shaped mould of 50mm diameter and 5mm thickness. The fibers are kept on the die and rollers are used for rolling process to keep the evenness of fiber to enhance the isotropic property and avoid the air bubbles. After that the preparation of unsaturated polyester resin with mixer of catalysts and accelerator were done and then poured in the mould at atmospheric temperature. After two hours the composites plate was removed from the mould and kept for post curing process in room temperature. Table 2 shows the designations of composites fabricated with varying fibers.

Table 2
Designation of Acacia and Cactus fiber composites

Designation	Fiber	Acacia fiber content (wt%)	Cactus fiber content (wt%)	Total fiber content (wt%)
UAFPC	Untreated Acacia fiber polymer composite	25%	-	25%
TAFPC	Treated Acacia fiber polymer composite	25%	-	25%
UCFPC	Untreated Cactus fiber polymer composite	-	25%	25%
TCFPC	Treated Cactus fiber polymer composite	-	25%	25%
UACFPC	Untreated Acacia and Cactus fiber polymer composite (Hybrid)	12.5%	12.5%	25%
TACFPC	Treated Acacia and Cactus fiber polymer composite (Hybrid)	12.5%	12.5%	25%

2.4. Electrical Analysis

The electrical properties test was conducted for both treated and untreated Acacia and Cactus fiber composites and its hybrid composites specimens. The dielectric constant experiments were carried out using LCR Impedance analyzer E4980A. The LCR meter is proficient of measuring upto a frequency of 2MHz. The contacting electrode method is used for analyzing the disc shaped specimens. As per the ASTM D150-11 standard [22], the measurements were done at varying frequency ranges from 1 KHz to 1 MHz. The frequencies of 3 Hz to 6 Hz are used for analysis of the dielectric constant and the values were recorded by Impedance analyzer.

The dielectric constant of a composite material is determined by materials ability to flow in a specific direction besides to store the charge when an electric field is externally applied to it through parallel capacitor plates [29]. The polarizability of the composite material decides the dielectric constant of the composite materials. Generally if polarizability is high in the molecule the dielectric constant also will be high. The interface between fiber and matrix decides the dielectric constant of the fiber reinforced polymer composites. At high frequencies the effects of atomic and electronic polarizations are immediate [30]. Relative permittivity which happens due to the presence of polar groups in the composite material is denoted by symbol ε. Dielectric strength is determined by the essential parameter dielectric constant of an insulated composite material.

Dissipation factor in a circuit represents the electrical loss in an insulation material when the voltage is applied. Dissipation factor, which is denote as tan δ is the ratio of the electrical power dissipated in a composite material specimen to the complete power in the circuit. The loss tangent is a measure of electrical energy which is converted to heat in an insulator specimen which helps to measure tan δ of a composite specimen. Loss factor (ε1), which is average power factor in a given period of time expresses the loss in distribution and transmission electrical energy [23]. Electrical conductivity which is an intrinsic property of a material is the ability to carry an electrical current in a material.

3. Results and Discussion

3.1 Dielectric Constant

The dielectric constant of both treated and untreated Acacia and Cactus fiber composites and its hybrid composites as a function of the logarithm of the frequency are shown in Figure 1. It was observed that the dielectric constant increased in low frequency and decreased in high frequency. The frequencies varied from 3 Hz to 6 Hz to measure the dielectric constant of all types of composites specimens. The dielectric constant value of 5.5 is observed at frequency of 3Hz for UAFPC and it decreased to 2.9 at frequency of 6Hz. In the case of TAFPC, the dielectric constant value is 5.2 in frequency of 3Hz which is slightly lesser than the UAFPC.

The dielectric constant value decreased to 2.6 in the frequency of 6Hz and compared with UAFPC when it was found that the TAFPC has given better result. In TAFPC, the dielectric constant value reduced than UAFPC from 5.45% to 10.34% with the log frequencies of 3Hz to 6Hz respectively. Moreover, the dielectric constant value 5.0 is observed in frequency of 3Hz for UCFPC and it decreased to 2.4 with increase of frequency to 6Hz while the frequency increased the dielectric constant decreased upto 52%. In the case of TCFPC specimen the dielectric constant value is 4.8 in 3Hz frequency which is 4% lesser than the UCFPC and in the 6Hz frequency the value is 2.2 which is 8.33% lesser than the UCFPC.

In hybrid composite of UACFPC, the dielectric constant value of 4.6 is found in the frequency of 3Hz then it decreased to 2.0 in 6 Hz frequencies. When the frequency increased to 6 Hz, the dielectric constant decreased to 56.52% compared to 3Hz. In the case of TACFPC the dielectric constant value is 4.5 in frequency of 3Hz which is slightly lesser than the UACFPC. The dielectric constant value decreased to 1.9 in the frequency of 6Hz and compared to UACFPC dielectric constant value is 5% is lesser. In TACFPC the dielectric constant value reduced from 2.17% to 5% in the frequencies 3Hz and 6Hz respectively when compared to UACFPC. In this experiment the alkali treated fiber composites shows the better dielectric constant results than the untreated fiber composites because of NaOH fiber surface treatment where the moisture absorption ability is reduced due to the reduction in the probability for the interface between polar –OH groups of cellulosic fibers and chemical treatment smashed the strong hydrogen bonding that made more reactive to the matrix [24].

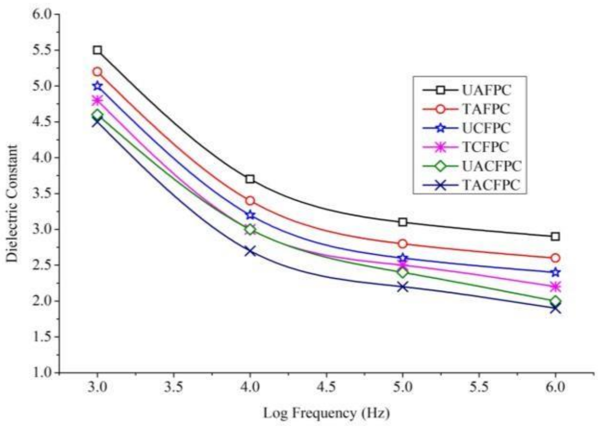

Fig. 1. Dielectric constant value of composites as a function of the logarithm of the frequency.

Comparison of alkali treated Acacia and Cactus fiber composite and its hybrid composite were made it is found that the hybrid composite showed the better dielectric constant which is 15.55% higher than the Acacia fiber composite (TAFPC) and 6.66% better than the Cactus fiber composite (TCFPC).Finally, in dielectric constant experiment the treated hybrid Acacia/Cactus fiber polymer composite confirmed the best results than other composites.

3.2. Dissipation Factor

The dissipation factor of both treated and untreated Acacia and Cactus fiber composite and its hybrid composites as a function of the logarithm of the frequency are shown in Figure 2. It was observed that the dissipation factor increased in low frequency and decreased in high frequency. The dissipation factor of 0.65 is observed at the frequency of 3Hz for UAFPC and it decreased to 0.39, 0.28 and 0.25 of dissipation factor at a frequency of 4Hz, 5Hz and 6Hz respectively. In the case of TAFPC the dissipation factor is 0.62 and 0.23 in frequencies of 3Hz and 6Hz respectively which is 4.61% to 8% lesser than the UAFPC.

Moreover dissipation factor of UCFPC is 0.6 which is observed in frequency of 3Hz and the value decreased to 0.21 at the frequency of 6Hz. In TCFPC, 0.59 dissipation factor is found in the 3Hz and 0.21 for 6Hz which is lesser than the UAFPC. In the case of hybrid composite, dissipation factor of UACFPC specimens is 0.57 at 3Hz frequency and reduced to 0.18 at frequency of 6Hz.

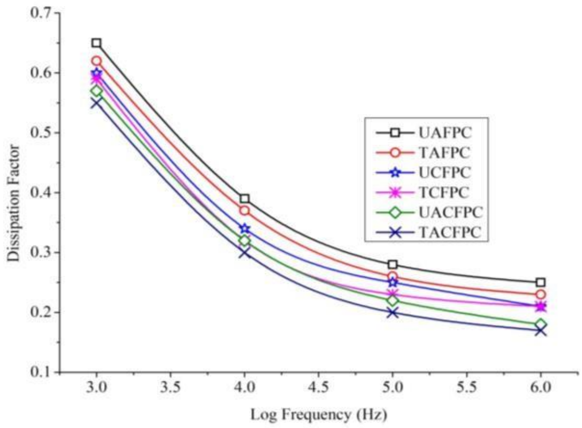

Fig. 2. Dissipation factor of composites as a function of the logarithm of the frequency.

In TACFPC the dissipation factor is reduced 3.5% to 5.5% frequency of 3Hz and 6Hz respectively when compared with UACFPC. Finally, the alkali treated hybrid composite specimens were found to have better dissipation factor.

3.3. Loss of factor

Figure 3 represents the loss factor of treated and untreated Acacia and Cactus fiber composite and its hybrid composites as a function of the logarithm of the frequency. The dielectric loss factor of alkali treated TACFPC is less which is the similar as the dielectric constant and dissipation factor mentioned earlier. TACFPC produced less loss factor 2.65 at frequencies increases.

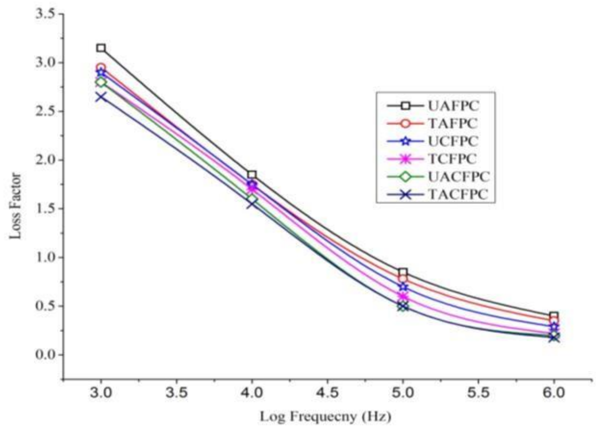

Fig. 3. Loss factor of composites as a function of the logarithm of the frequency.

3.4. Electrical Conductivity

Figure 4 represents the electrical conductivity of treated and untreated Acacia and Cactus fiber composite and its hybrid composites as a function of the logarithm of the frequency. The dielectric conductivity of all the Acacia and Cactus composite fibers and its hybrid composites increased with the increase in frequency. The minimal electrical conductivity was found in the low frequency of the composites. Experiment of TACFPC found that the electrical conductivity was better value (low) at all frequency compared to the other composite specimens which are used as insulated materials.

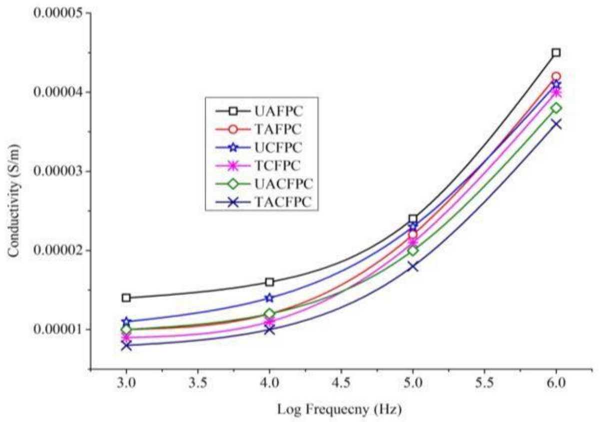

Fig. 4. Electrical Conductivity of composites as a function of the logarithm of the frequency

4. Conclusion.

The electrical properties of alkali treated and untreated Acacia and Cactus fiber composites and its hybrid composites were assessed. Dielectric constant decreased with an increase in the frequency for all the composite specimens. The highest values of dielectric constant in the lower frequency range were accredited to the interfacial polarization. The dielectric constant, loss factor, dissipation factor and conductivity decreased with chemically treated composite specimens due to the increase in the interfacial adhesion between the fibers and matrix. And also the chemical treatment reduced the hydrophilic nature of Acacia and Cactus fibers. In general, the Acacia/Cactus reinforced polyester hybrid composite specimens exhibited superior values of electrical properties compared to other composites. Considering the above experimented properties it is recommended that the composite materials can be used in industries as insulation materials for the safety purpose.

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References

1. Ahmed, K.S. and Vijayarangan, S., 2008. Tensile, flexural and interlaminar shear properties of woven jute and jute-glass fabric reinforced polyester composites. Journal of materials processing technology, 207(1-3), pp.330-335.
2. Idicula, M., Neelakantan, N.R., Oommen, Z., Joseph, K. and Thomas, S., 2005. A study of the mechanical properties of randomly oriented short banana and sisal hybrid fiber reinforced polyester composites. Journal of applied polymer science, 96(5), pp.1699-1709.
3. T.P.Sathishkumar, P.Navaneethakrishnan, S,Shankar., "Tensile and flexural properties of snake grass natural fiber reinforced isophthallic polyester composites"., Composites Science and Technology 72(2012) 1183-1190.
4. Sreekala, M.S., George, J., Kumaran, M.G. and Thomas, S., 2002. The mechanical performance of hybrid phenol-formaldehyde-based composites reinforced with glass and oil palm fibres. Composites science and technology, 62(3), pp.339-353.
5. Towo, A.N. and Ansell, M.P., 2008. Fatigue evaluation and dynamic mechanical thermal analysis of sisal fibre–thermosetting resin composites. Composites Science and Technology, 68(3-4), pp.925-932.
6. Geethamma, V.G., Kalaprasad, G., Groeninckx, G. and Thomas, S., 2005. Dynamic mechanical behavior of short coir fiber reinforced natural rubber composites. Composites Part A: Applied Science and Manufacturing, 36(11), pp.1499-1506.
7. John, MJ & Thomas, S 2008, 'Biofibres and biocomposites', Carbohydrate polymers, vol 71, no.3, pp. 343-364.
8. Tripathy, S.S., Jena, S., Misra, S.B., Padhi, N.P. and Singh, B.C., 1985. A study on graft copolymerization of methyl methacrylate onto jute fiber. Journal of applied polymer science, 30(4), pp.1399-1406.
9. Ibrahim, N.A., Hadithon, K.A. and Abdan, K., 2010. Effect of fiber treatment on mechanical properties of kenaf fiber-ecoflex composites. Journal of Reinforced Plastics and Composites, 29(14), pp.2192-2198.
10. Edeerozey, A. M., Akil, H. M., Azhar, A. B., & Ariffin, M. Z. (2007). Chemical modification of kenaf fibers. Materials Letters, 61(10), 2023-2025.
11. Gomes, A., Matsuo, T., Goda, K. and Ohgi, J., 2007. Development and effect of alkali treatment on tensile properties of curaua fiber green composites. Composites Part A: Applied Science and Manufacturing, 38(8), pp.1811-1820.
12. Akhtar, M.N., Sulong, A.B., Radzi, M.F., Ismail, N.F., Raza, M.R., Muhamad, N. and Khan, M.A., 2016. Influence of alkaline treatment and fiber loading on the physical and mechanical properties of kenaf/polypropylene composites for variety of applications. Progress in Natural Science: Materials International, 26(6), pp.657-664.
13. Birley AW, Hayworth B, Batchelor J. Physics of plastics processing, properties and materials engineering. New York: Hanser Publishers; 1992.
14. Miyauchi S, Togashi E. The conduction mechanism of polymer-filler particles. J Appl Polym Sci 1985;30:2743–51.
15. Burton LC, Wang K, Zhang T. Dynamic electrical and electromechanical properties of carbon-black-loaded rubber. Rub Chem Technol 1989;62:838–49.
16. Hong CK, Wool RP. Low dielectric constant material from hollow fibers and plant oil. J Nat Fibers 2004;1(2):83–92.
17. Pothan, L.A., George, C.N., Jacob, M. and Thomas, S., 2007. Effect of chemical modification on the mechanical and electrical properties of banana fiber polyester composites. Journal of composite materials, 41(19), pp.2371-2386.
18. Pathania D, Singh D. A review on electrical properties of

fibre reinforced polymer composites. Int J Theor Appl Sci 2009;1(2):34–7.
19. Cabral H, Cisneros M, Kenny JM, Vazquez A, Bernal CR. Structure–properties relationship of short jute fibre reinforced polypropylene composites. J Compos Mater 2005;39(1):51–65.
20. Jacob, M., Varughese, K.T. and Thomas, S., 2006. Dielectric characteristics of sisal–oil palm hybrid biofibre reinforced natural rubber biocomposites. Journal of materials science, 41(17), pp.5538-5547.
21. Joseph S, Thomas S. Electrical properties of banana fiber-reinforced phenol formaldehyde composites. J Appl Poly Sci 2008;109:256–63.
22. Jayamani, E., Hamdan, S., Rahman, M.R. and Bakri, M.K.B., 2015. Dielectric properties of lignocellulosic fibers reinforced polymer composites: Effect of fiber loading and alkaline treatment. Materials Today: Proceedings, 2(4-5), pp.2757-2766.
23. Sreekumar, P.A., Saiter, J.M., Joseph, K., Unnikrishnan, G. and Thomas, S., 2012. Electrical properties of short sisal fiber reinforced polyester composites fabricated by resin transfer molding. Composites Part A: Applied Science and Manufacturing, 43(3), pp.507-511.
24. George, G., Joseph, K., Nagarajan, E.R., Jose, E.T. and George, K.C., 2013. Dielectric behaviour of PP/jute yarn commingled composites: Effect of fibre content, chemical treatments, temperature and moisture. Composites Part A: Applied Science and Manufacturing, 47, pp.12-21.
25. Lai, C.Y., Sapuan, S.M., Ahmad, M., Yahya, N. and Dahlan, K.Z.H.M., 2005. Mechanical and electrical properties of coconut coir fiber-reinforced polypropylene composites. Polymer-Plastic Technology and Engineering, 44(4), pp.619-632.
26. Jayamani, E., Hamdan, S., Rahman, M.R. and Bakri, M.K.B., 2014. Comparative study of dielectric properties of hybrid natural fiber composites. Procedia Engineering, 97, pp.536-544.
27. Singha, A.S., Rana, A.K. and Jarial, R.K., 2013. Mechanical, dielectric and thermal properties of Grewia optiva fibers reinforced unsaturated polyester matrix based composites. Materials & Design, 51, pp.924-934.
28. Dash, B.N., Rana, A.K., Mishra, S.C., Mishra, H.K., Nayak, S.K. and Tripathy, S.S., 2000. Novel low-cost jute–polyester composite. II. SEM observation of the fractured surfaces. Polymer-Plastics Technology and Engineering, 39(2), pp.333-350.
29. Mehta, N.M. and Parsania, P.H., 2006. Fabrication and evaluation of some mechanical and electrical properties of jute/biomass based hybrid composites. Journal of Applied Polymer Science, 100(3), pp.1754-1758.
30. Tomlal, E.J., Thomas, P.C., George, K.C., Jayanarayanan, K. and Joseph, K., 2010. Impact, tear, and dielectric properties of cotton/polypropylene commingled composites. Journal of Reinforced Plastics and Composites, 29(12), pp.1861-1874.