Green dielectric solids using PLA and luffa fiber modified by the medical linear accelerator

Sonismita Dalai
Odisha University of Agriculture and Technology
Chhatrapati Parida (sivaji_1976@yahoo.co.in)
Odisha University of Agriculture and Technology https://orcid.org/0000-0002-6465-8560

Research Article

Keywords: PLA, LC fiber,electron beam, dielectric constant, ac conductivity

Posted Date: July 15th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-660508/v2

Green dielectric solids using PLA and *luffa* fiber modified by the medical linear accelerator

Sonismita Dalai, Chhatrapati Parida*

Department of physics, Odisha University of Agriculture and Technology, Bhubaneswar,India-751003

***sivaji_1976@yahoo.co.in**

Abstract

Biodegradable electronic devices are presently in command in various sectors mainly in the health care system. The present work comprehends the dielectric properties of biodegradable composites made from biodegradable polymer poly (lactic) acid (PLA) and natural fiber of *luffa cylindrica*l (LC) fabricated using micro compounding and injection molding. LC fibers are agricultural waste, rich in cellulose.LC fibers were exposed to a 6 MeV electron beam of doses 0.5Gy, 1.0Gy, 2.0Gy, 4.0Gy, and 10.0 Gy generated from a medical linear accelerator(LINAC) in presence of air. Such low doses are normally used for the treatment of cancer patients and not for modifying polymers where doses in the range of 20-200KGy are used. The effect of such low irradiation dose on fiber and study if any significant changes taking place is the innovative aspect of the present work. The effects of irradiation dose on dielectric constant and ac conductivity were investigated at different temperatures 26^0C, 40^oC, 60^oC, and 80^oC while keeping the frequency constant. The increase in dielectric constant from 57 in virgin PLA at 26^0C,500Hz to a maximum of 84 in the composite sample due to reinforcement of low dose irradiated LC fibers recording a 49% increase is an important result of the investigation.

Keywords: PLA; LC fiber; electron beam;dielectric constant;ac conductivity

1.Introduction

Biodegradable material has recently plunged a major impact in biomedical terrains such as drug delivery, therapeutics, and tissue engineering. There is always a need for biodegradable dielectric material through which electrical signals can be transmitted in myocardial tissue and neurons. Biodegradable bioimplant devices for the human body are currently in high yearning. The need for biodegradable electronic devices arises to eliminate the problem of disposal of synthetic electronic device waste which causes severe environmental problems like soil pollution and contamination[1,2]. The current research uses the fruit of LC, a common tropical fruit that is a waste, as reinforcement in completely biodegradable PLA matrix producing green composites.PLA has captivated substantial research interests due to its biodegradable and biocompatible nature. The LC fibers are rich in cellulose(60%), cost-effective, readily available with low CO_2 emission along with high electrical resistance, good thermal and acoustic insulating properties. Most importantly they are biodegradable and can be recycled [3-6]. However, the LC fibers are hydrophilic due to the presence of cellulose, hemicellulose, and lignin, with a tendency to absorb moisture from the surrounding making them less reactive having poor compatibility with the polymer matrices during the fabrication of composite materials. Thus fiber modification is necessary before its use as reinforcement[4-6]. Ionizing radiation for modification of natural fiber holds great consideration because of no use of chemicals, low processing time leading to energy saving, clean waste-free procedure leaving no bad impact on the environment. Electron beams are used in radiation processing mostly, which bring significant structural changes in the fiber with a very low irradiation dose [4,7,8]. Celluloses, which are the major component of plant fiber, are long-chain polymers consisting of identical glucopyranose units which are linked to their neighbor by glucosidic linkage. When natural fibers rich in celluloses are exposed to the electron beam and gamma rays, free radicals are formed on the surface of the fiber leading to enhanced bonding between fiber and matrix. Crosslinking and chain scission are two major chemical changes observed when the cellulose-rich natural fiber is irradiated with an electron beam and gamma rays[4,9]. Further, the increase in surface area due to the defibrillation of cellulose fibers enhances the compatibility between fiber and matrix. The interaction of electrons with the solid can be soft interactions(excitation) or hard interactions or knockout interactions. When these radiations interact with solid molecules, they transfer energy to the solid molecules leading to the formation of reactive molecules in the excited states. This can be represented as

$$\mathrm{e} + \mathrm{M} \rightarrow \mathrm{M}^{+} + 2\mathrm{e}^{-} \qquad (1)$$

where M is the solid molecule and M^{+} is the ionized solid molecule as well as an exciting solid molecule. Finally, the irradiated material is ionized during electron beam irradiation and a large number of electrons are available on the surface, thereby generating many free radicals. The presence of free radicals and monomers enhances the chemical bonding between irradiated LC fiber and matrix when the fiber is used as reinforcement during the fabrication of composites[8-10].

Normally polymers are modified with irradiation doses in the range from 20-200KGy and incase of some highly sensitive biopolymers, changes are observed from 1KGy irradiation dose. Cellulose, the major component in plant fiber is usually rather resistant to irradiation. The most significant and innovative matter concerning this investigation is doses applied for modification of LC fiber at the level from 0.5Gy to 10.0Gy. The objective behind this work is to detect whether any significant changes are occurring at this low level of doses. Such low doses are used for the treatment of cancer patients and not normally for modifying polymers. Thus this is an innovative way of modifying the surface of LC fiber using radiation obtained from medical linac. Electrons are accelerated to the high energy of 6MeV The different components of a linac are given in **Figure 1**.

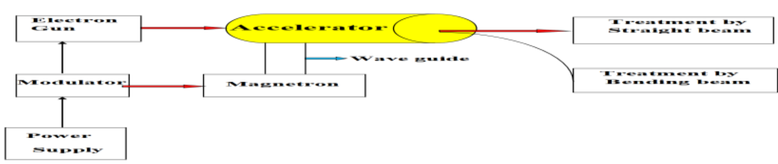

Fig 1:Schematic diagram of a medical linac

As shown in **Fig. 1**, the linear accelerators are connected to a power supply, supplying alternating currents to the modulator. The modulator converts the alternating current to a direct current. The modulator is a pulse modulator that converts the dc voltage in terms of pulses of a few microseconds duration. Linacs accelerate electrons too few mill volts of energy in a pulsed manner and not in a continuous manner. The output of the pulse modulator is fed to the electron gun as well as to the magnetron. The magnetron generates microwaves required to accelerate electrons to 6MeV coming from an electron gun. These accelerated electron beams are further directed to a target having high Z to generate X-rays/gamma rays by bremsstrahlung interactions using microwave technology.

All agricultural materials such as natural fibers, foods conduct electric currents to some extent. Knowledge of the dielectric properties of these materials will determine the distribution of electromagnetic fields in the materials in presence of the external alternating field. How rapidly a material can be heated by radio waves or microwaves, can be ascertained from the evaluation of dielectric properties. All crystalline materials consist of two sublattices, ordered lattices exhibiting normal oscillations obeying Lyddane-Sachs-Teller (LST) model and disordered lattices having random oscillations obeying Debye's relaxations. Thus the crystal when exposed to an external electric field is polarized in different ways .and the total polarization is expressed as $p = p' + p_d$. The p' is the polarization due to ordered motion having a contribution from dipole polarization, atomic polarization, and ionic polarization while

p_d is the polarization due to disordered motion caused by jumping of particles between two positions also known as orientation polarization. ε_r is the dielectric constant of the material and is a sum of two terms contributing from ordered oscillation(ε') and disordered oscillation(ε_d) i.e $\varepsilon_r = \varepsilon' + \varepsilon_d$

Here in both ordered and disordered sublattices, particles oscillate as harmonic oscillators but in an ordered lattice. There occurs resonance for disordered sublattice and relaxation for ordered sublattice.

The relaxation time of the dipoles can be related to the energy barrier between two available states as $\tau = \tau_0 e^{\frac{\Delta U}{KT}}$ ……………(2).

ΔU is the energy barrier between the two states and T is the temperature. As temperature increases, the relaxation time decreases leading to increased relaxation frequency.

The dielectric constant of a material due to a disordered state is a complex number having both a real part and an imaginary part. $\varepsilon_d = \varepsilon' - j\varepsilon''$ The real part ε' is the dielectric constant which is a measure of the ability of the material to store energy in presence of an external electric field. The imaginary part ε'' is dielectric loss which indicates the ability of the material to absorb or dissipate energy obtained by conversion of electrical energy to heat energy. It shows the tendency of the material to be heated in presence of an electromagnetic field of different frequencies. Both the real part and imaginary part tells about the polarizing ability of the material in presence of an external electric field. The frequency dependence of the real part and imaginary part of the dielectric constant can be obtained from Debye s model[11,12].

$$\varepsilon_d = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 + j\omega\tau}, \qquad \text{……………………………………..(3)}$$

Separating the real part and imaginary part we get

$$\varepsilon' = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 + (\omega\tau)^2} \qquad \text{………………………………………………………..(4)}$$

$$, \varepsilon'' = \frac{(\varepsilon_s - \varepsilon_\infty)\omega\tau}{1 + (\omega\tau)^2} \qquad \text{……………………………………………………….(5)}$$

ε_∞ is the dielectric constant of the material at a very high frequency of the applied electric field where the orientation of polar molecules is not possible due to much less time interval and ε_s is the static dielectric constant at zero frequency of the applied electric field. In addition to the real and imaginary part of the dielectric constant, the knowledge of the ac conductivity of a material is essential, whose expression can be obtained using Maxwell electromagnetic wave equation.

The displacement current in the dielectric is expressed as $j = (\omega\epsilon_0\epsilon'')E = \sigma E$

Where

$\sigma = (\omega\epsilon_0\epsilon'')$ is known as ac conductivity of the material.

The dielectric behavior of material relates to the intrinsic interactions of electromagnetic waves with matter. The biodegradable nature of both PLA and natural fibers of LC fascinates us to carry out the work and to study the complex dielectric properties of the prepared blended materials with variation in irradiation dose, temperature, and frequency.

2.Materials and methods

2.1 Material

Polylactic acid (PLA) of grade 4042D (molecular weight Mw ~ 6, 00, 000) was acquired from Nature Works, USA. The LC fibers were obtained from the local forest area.

2.2 Electron beam irradiation

The electron beam of energy 6 MeV generated from the medical LINAC (Millenium True Beam Linear Accelerator, Varian) installed in Health Care Global Panda Cancer Hospital, Cuttack, India. The LC fiber was mounted below a cotton gauge of 3-inch thickness and was irradiated with a rate of 600MU/min to attain doses of 0.5Gy, 1.0Gy, 2.0Gy, 4.0Gy, and 10.0Gy.

2.3 Composite processing and fabrication

The PLA pellets and the electron beam irradiated LC fibers were left for drying in a vacuum at 80° C for 24 h before use. The PLA and LC fiber were mixed mechanically at 100 rpm with a micro compounding molding equipment at 170°C for 10 minutes. After extrusion through a preheated cylinder, the molten composite samples were transferred to the mini injection molder to obtain the desired specimen samples for studying various properties.

2.4 **Variety of samples for characterization**

Composite samples were prepared with PLA matrix and different doses of electron beam irradiated LC fibers. in E1, E2, E3, E4, E5 samples, the PLA and 5% wt fibers are mixed with electron beam irradiation dose of 0.5Gy, 1.0Gy, 2.0Gy, 4.0Gy, and 10.0Gy respectively.

2.5 X-Ray diffraction

WXRD/SHIMADZU/JAPAN, goniometer facilitated with scintillation counter records t the X-ray diffractograms at 26˚C with Bragg's angle ranging from $10^0$to 80^0 using Ni filtered Cu Kα radiation of a wavelength of 0.1542 nm.

2.6 Dielectric properties measurements

Rectangular specimens of 10mm × 10mm × 2mm were prepared and coated with conductive silver paint for the study of electrical properties. The test samples were fixed between two electrodes and kept inside the sample holder. Measurements were carried out at 26^0C,40^0C, 60^0C, and 80^0C temperature keeping constant frequency from 500 Hz to 5MHz to examine various dielectric properties such as dielectric constant and ac conductivity.

3. Results and discussion

3.1 X-ray diffraction

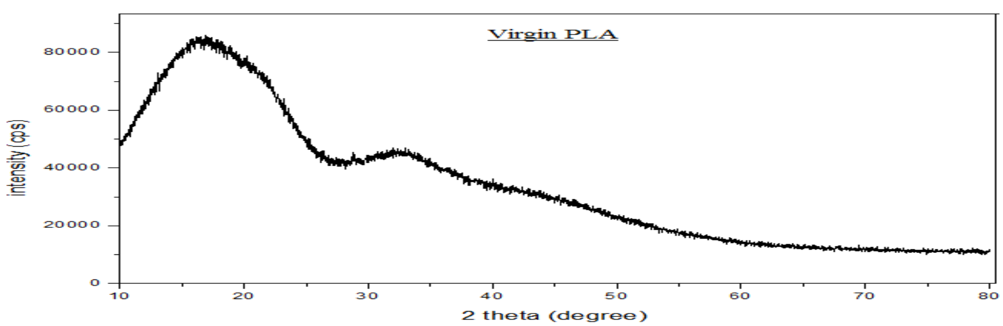

Fig. 2: XRD pattern of virgin PLA

Fig. 2 depicts the XRD pattern of virgin PLA. Fig.2 exhibits diffused diffraction peaks at18^0 and 32^0 rather than sharp crystalline peaks. Two broad peaks in PLA are attributed to the amorphous nature of PLA and the presence of two crystalline structures.

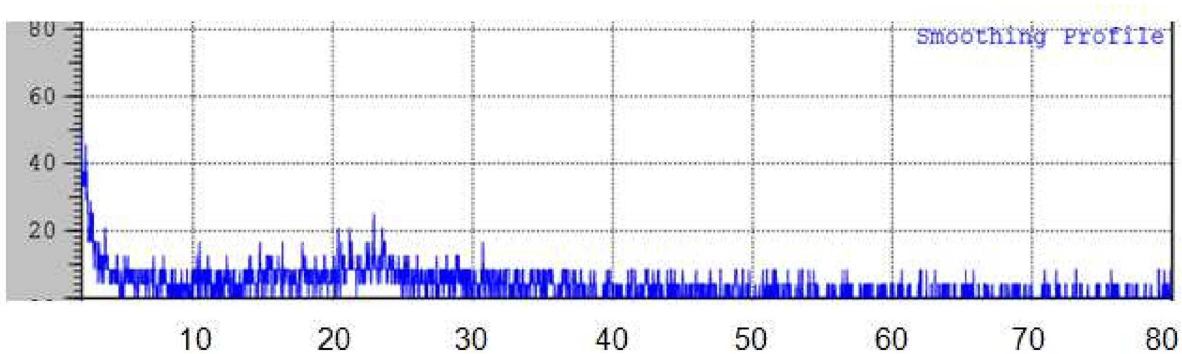

Fig. 3: XRD spectra of composite sample E2 (PLA with 5% fiber having electron beam irradiation dose 1.0Gy)

Fig. 3 gives the XRD pattern of LC fiber irradiated by 1.0Gy. The XRD spectra have no distinct peaks owing to the destruction of crystallinity of LC fiber due to radiation at a 1.0Gy beam. The highly amorphous nature of the fiber increases the number of polar monomers leading to increase fiber roughness and subsequent generation of numerous voids. The roughness of the irradiated LC fiber and numerous voids are expected to enhance the bonding between fiber and matrix during the composite synthesis.**Fig. 4** shows the XRD spectra of composites using PLA as matrix and 5wt% electron beam irradiated (1Gy)LC fiber as reinforcement. The diffractogram of **Fig.4** shows the presence of broad peaks around 20.90 ^{0} and 39.23^{0} .

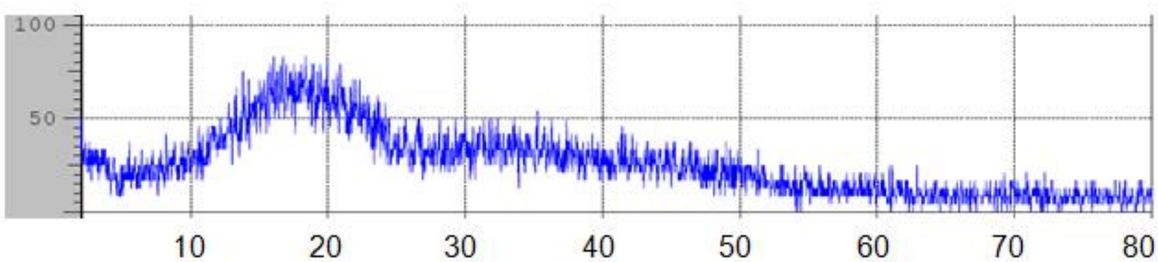

Fig.4:XRD pattern of 1 Gy electron beam irradiated LC fiber composite (sample E2)

The shifting of peaks from 18^{0} and 32^{0} in the XRD pattern of PLA shown in **Fig.3** to 20.90 ^{0} and 39.23^{0} in composite sample E2 shown in Fig.**4** is indicative of chemical bonding between irradiated LC fiber and PLA matrix.

3.2 Effect of temperature on dielectric constant and ac conductivity of electron beam irradiated LC fiber composites

Table 1 lists the values of the dielectric constant of virgin PLA matrix, composite samples E1, E2, E3, E4, and E5 at temperatures of 26^{0}C, 40^{0}C, 60^{0}C ,80^{0}C at frequency 500Hz, 5KHz, 5MHz respectively.

Table 1: Dielectric constant at different temperature and different frequencies

Sample	**At frequency 500Hz**				**At frequency 5KHz**				**At frequency 5MHz**			
	26^{0}C	**40^{0}C**	**60^{0}C**	**80^{0}C**	**26^{0}C**	**40^{0}C**	**60^{0}C**	**80^{0}C**	**26^{0}C**	**40^{0}C**	**60^{0}C**	**80^{0}C**
B0(virgin PLA)	57	113	120.	108.	38 ±	110 ±	116.2	104.2	12	77 ±	82 ±	92 ±

	± 2.90	± 3.66	3 ± 3.65	3 ± 3.00	1.90	1.43	2 ± 1.33	2 ± 1.02	± 0.4	1.01	1.02	0.92
E1(0.5GyLCfiber/PLA)	71.9 ± 2.9	19 ± 0.3	30 ± 0.3	65 ± 0.3	68.5 ± 0.3	17.4 ± 0.2	26.2 ± 0.3	58.4 ± 0.3	66. ± 0.3	16. ± 0.1	18. ± 0.1	54.1 ± 0.2
E2(1.0GyLCfiber/PLA)	84.7 ± 2.8	63 ± 2.8	65 ± 2.7	63 ± 2.7	73.7 8 ± 2.6	55 ± 2.7	59 ± 2.8	57 ± 2.8	45 ± 1.9	16 ± 0.8	12 ± 0.8	18 ± 0.8
E3(2.0GyLCfiber/PLA)	73.1 ± 3.0	49.1 ± 2.6	55.2 ± 2.6	76.5 ± 2.8	42 ± 2.6	50 ± 2.6	58 ± 2.5	70 ± 2.8	56 ± 2.5	15.7 ± 0.8	14 ± 0.9	19.5 ± 1.1
E4(4.0GyLCfiber/PLA)	64.9 ± 2.4	64 ± 2.4	68 ± 2.5	71 ± 2.4	61. ± 2.4	59.61 4 ± 2.4	60.38 7 ± 2.6	63.22 ± 2.4	48 ± 2.4	45.4 6 ± 2.5	49.8 0 ± 2.6	49.78 5 ± 2.6
E5(10.0GyLCfiber/PLA)	70 ± 2.5	27 ± 1.2	28. ± 1.2	54. ± 1.8	61 ± 1.8	23 ± 1.9	21 ± 1.7	53 ± 1.9	17 ± 0.9	14 ± 0.4	18 ± 0.4	20 ± 0.8

Note: The values represent mean ± SD of 10 replicates

Table 1 betokens that the dielectric constant for virgin PLA is 57 at 500Hz at a temperature of 26^0C and it decreases to 38 at 5KHz frequency and 12 at 5MHz frequency respectively keeping the temperature constant at 26^0C . The similar dielectric dispersion is well exhibited by all other composite samples obeying Debyes model as given in expression 2 i.e $\varepsilon' = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1+(\omega\tau)^2}$

At low frequency, the dielectric constant ε' is nearly the same as the static dielectric constant ε_s . With the increase in the frequency of the applied electric field ω , ε' decreases and at high-frequency ε' approaches ε_∞ .Polar -OH groups and ester (polar molecule) linkage present in PLA and LC fiber contribute to high orientation polarization at low frequency because there is sufficient time interval for which the dipoles or polar groups present in the composite samples realign themselves in resonance with the applied electric field. However when the frequency increases, the time interval decreases, and the polar groups were not able to polarize following the external electric field leading to a decrease of dielectric constant.

It is observed from **Table 1** that the dielectric constant of virgin PLA (B0) is 57 at a temperature of 26^0C at a frequency 500 Hz. It first increases to 113 at 40^0C and 120.3 at 60^0C keeping frequency unchanged at 500Hz and then decreases to 108 at 80^0C. PLA contains a polar hydroxyl group(-OH) in its backbone. When the temperature rises, the thermal energy of the dipoles increases leading to an increase in orientation polarization and an increase in dielectric constant. The initial increase of dielectric constant with temperature rise has also bequest from dc conductivity and space charge polarization at the grain boundaries.The dc conductivity varies with temperature $\sigma_{dc} = \sigma_0 \exp(-\frac{\Delta U}{KT})$ as. Dc conductivity increases with an increase in temperature leading to an increase in dielectric constant. However, with the rise of temperature beyond a certain temperature, the amount of moisture present in the sample decreases leading to a decrease in the number of polar groups(-OH) and orientation polarization resulting in a decrease of dielectric constant. [11,12] . The temperature at which the dielectric constant starts decreasing is the transition temperature and it represents a relaxation. With the rise of temperature beyond the transition temperature, the chemical bonds vibrate more vigorously causing a decrease of dipole moment and orientation polarisation of the functional groups obeying Debyes relaxation given by the expression $\tau = \tau_0 e^{\frac{\Delta U}{KT}}$. Where τ is the relaxation time and T is the temperature. When the temperature goes beyond the transition region, relaxation time decreases with the increase of temperature. The dipoles couldn't orient effectively with a decrease in relaxation time under the external electric field leading to a decrease of dielectric constant.

However, for composite samples, E1, E2, E3, E4 & E5, the dielectric constant is enhanced as compared to that of virgin PLA at room temperature 26^0C & at frequency 500Hz. For the fixed wt of irradiated LC fiber(5wt%) in the PLA matrix, the dielectric constant increases from 57 in virgin PLA matrix to 71.98 in composite sample E1 (0.5 Gy irradiatedLC fiber/PLA), 84.79 in E2 (1.0 Gy irradiatedLC fiber/PLA),. 73.16 in E3 (2.0 Gy LCirradiated fiber/PLA) , 64.92 in E4 (4.0 Gy irradiated LCfiber/PLA) and 70 in E5 (10.0 Gy irradiated LCfiber/PLA). The maximum increase of dielectric constant is 49% for composite sample E2, where the LC fiber is irradiated with a 1.0 Gy electron beam irradiation dose. The increase in the dielectric constant of composite samples as compared to that of virgin PLA at 26^0C, 500Hz is contributed by chain scission of celluloses and hemicelluloses in LC fiber induced by electron beam irradiation. The chain scission breaks the long-chain polymers of cellulose into fragments. The portability of functional groups or polar groups increases the polarization leading to enhanced dielectric constant. However when the irradiation dose increases beyond 1.0 Gy, the dielectric constant decreases from 84.79 in E2 (1.0 Gy irradiated fiber) to 73.16 in E3 (2.0 Gy irradiated fiber), 64.92 in E4 (4.0 Gy irradiated fiber), and 70 in E5 (10.0 Gy irradiated fiber). The decrease in dielectric constant beyond irradiation dose 1.0 Gy may be due to cross-linking induced by the electron beam irradiation. The irradiation process on fiber induces both chain scission and cross-linking. The increase of the dielectric constant could be explained by the chain scission process while a decrease of the dielectric constant could be explained by cross-linking. Due to cross-linking, the different smaller fragments are linked together leading to a decrease in mobility of polar molecules. Thus decrease in mobility decreases the dielectric constant[11-14].

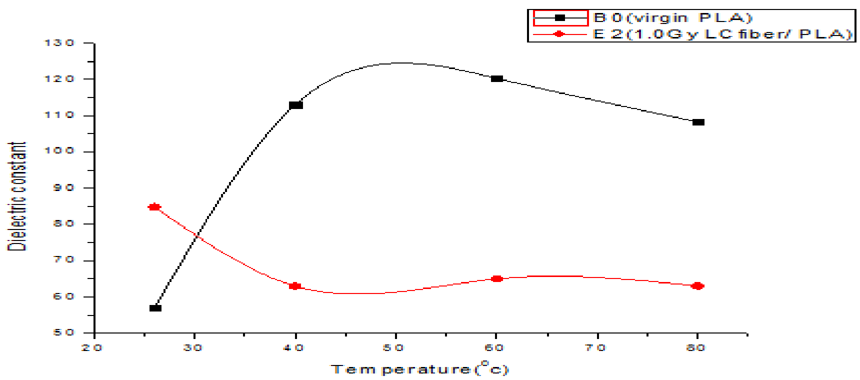

Fig.5:Variation of dielectric constant with temperature of virgin PLA and composite sample E2at frequency 500 Hz

Fig. 5 gives the variation of the dielectric constant of virgin PLA and composite sample E2 with temperature. The dielectric constant of matrix PLA initially rises with temperature followed by decreasing after a certain transition temperature. For composite sample E2, the dielectric constant at 26^0C is 84.79. But with the rise in temperature to 40^0C , it decreases to 63. When LC fibers are reinforced into the matrix, the number of –OH groups is increased. With the increase in temperature, the moisture present in the sample vaporizes leading to a decrease in the number of polar groups and hence orientation polarization. Beyond 40^0C, the dielectric constant of E2 rises to 65 at 60^0C owing to an increase in greater mobility of polar molecules. Similar trends are observed for all other composite samples with variations in temperatures. As perceived from table 1, the dielectric constant varies from a minimum of 12 for composite sample E2 at 5MHz frequency, 60^0C to a maximum of 116.2 for virgin PLA at 5KHz frequency,

60^0C. Thus the virgin PLA and the composite samples can be tunable to a wide range of variation in dielectric constant opening up many possibilities for future applications.

Table 2 betokens the values of ac conductivity of electron beam irradiated LC fiber/PLA composites with varying temperatures and at different frequencies.

Table:2 Values of ac conductivity PLA and composite samples with varying temperature and at different frequencies.

Sample	**AC conductivity (*10^{-9}ohm^{-1}m^{-1}) At frequency 500Hz**				**AC conductivity (*10^{-9}ohm^{-1}m^{-1}) At frequency 5KHz**				**AC conductivity (*10^{-9}ohm^{-1}m^{-1}) At frequency 5MHz**			
	26^0C	40^0C	60^0C	80^0C	26^0C	40^0C	60^0C	80^0C	26^0C	40^0C	60^0C	80^0C
B0(virgin PLA)	5.68 ± 0.4	0.366 ± 0.04	0.822 ± 0.04	0.127 ± 0.02	98.1 ± 2.8	8.45 ± 0.9	1.15 ± 0.2	0.291 ± 0.08	33300 ± 904	4600 ± 120	2840 ± 102	30600 ± 902
E1(0.5GyLCfiber/PLA)	1.53 ± 0.2	0.983 ± 0.03	1.40 ± 0.2	1.75 ± 0.3	7.75 ± 0.4	30.9 ± 0.8	2.64 ± 0.1	6.67 ± 0.2	4030 ± 98	6450 ± 120	12300 ± 130	35600 ± 370
E2(1.0GyLCfiber/PLA)	3.96 ± 0.06	96.6 ± 1.4	202 ± 2.2	101 ± 1.4	35.3 ± 0.6	328 ± 1.8	359 ± 1.8	360 ± 2.0	11400 ± 120	37000 ± 980	9030 ± 120	53200 ± 1020
E3(2.0GyLCfiber/PLA)	6.35 ±	3.85 ±	6.21 ±	6.57 ±	115 ±	0.612 ±	39.6 ±	8.87 ±	26100 ±	16400 ±	16100 ±	16100 ±

	0.8	0.8	1.2	1.2	10	0.04	0.8	0.2	540	900	240	240
E4(4.0GyLCfiber/PLA)	2.65 ± 0.2	2.57 ± 0.2	4.10 ± 0.2	3.35 ± 0.2	17.6 ± 0.3	14.3 ± 0.2	36.3 ± 0.2	11.9 ± 0.2	6940 ± 120	3160 0± 900	3630 0± 900	1500 0± 560

Note: The values represent mean ± SD of 10 replicates

Table 2 depicts that the ac conductivity of the virgin PLA is 5.68nSi at 500Hz and 26^{0}C. It changes with the incorporation of electron beam irradiated LC fiber into the matrix. Maximum ac conductivity is observed for composite sample E3(2.0Gyirradiated LC fiber/PLA) at 6.35nSi. This increase of conductivity may be attributed due to chain scission in the polymeric chain of fiber at that irradiation dose. But for other composite samples E1, E2, E4, E5, breakage of (C-C) and (C-H) bonds occur creating barriers against the mobility of charge carriers resulting in a decrease in the conductivity of composite samples as compared to virgin PLA. Further**, table 2** portrays that the ac conductivity of virgin PLA and composite samples increase with an increase in frequency. With the increase in the frequency of the applied electric field, the dipole molecules oscillate more frequently leading to enhanced ac conductivity. With the rise in temperature at low frequency, the dielectric constant of virgin PLA decreases from 5.68nSi at 26^{0}C to 0.127nSi at 80^{0}C owing to increased random motion at higher temperatures causing decreased mobility. However, for composite samples, the variation of ac conductivity with temperature follows an irregular manner owing to the multitude of factors like the presence of fiber, interfacial bonding between fiber and matrix, chain scission, cross-linking, and variation in the frequency of the applied electric field. The maximum ac conductivity is 53200 nSi for composite sample E2 at 80^{0}C and frequency 5MHz and the minimum ac conductivity is found to be 0.127nSi for virgin PLA at 500Hz and 80^{0}C. Again the observance of such a wide range of ac conductivity explores many opportunities in the use of these composite materials.

4 Conclusions

The present exploration delineated the fabrication of an ecofriendly, green, biodegradable dielectric material utilizing an agro-waste LC fiber and biodegradable PLA. Values of dielectric constant and ac conductivity of virgin PLA matrix and the composites made using irradiated LC fibers/PLA matrix were experimentally evaluated. The dielectric constant of virgin PLA was reported 57 and it increased from 57 to a maximum of 84.79 with reinforcement of electron beam irradiated LC fiber in the matrix reporting increase in dielectric constant by 49% at frequency 500Hz and temperature 26^0C. This is an important result showing that changes are detected in the dielectric constant at this level of doses from 0.5Gy to 10Gy and at energy 6MeV, normally used to treat cancer patients. Further, the dielectric constant of the composite samples can be tuned to vary from 12 for composite sample E2 at 5MHz frequency at 60^0C to a maximum of 116.2 for virgin PLA at 5KHz frequency at 60^0C. Similarly, the ac conductivity varies from a maximum of 53200 nSi for composite sample E2 at 80^0C and frequency 5MHz to a minimum ac conductivity is of 0.127nSi for virgin PLA at 500Hz and 80^0C. This wide range of tunability of dielectric constant and ac conductivity with variation in irradiation dose, frequency, and temperature opens up many possible applications in the future. Connectors for electrically responsive neurons and cardiac cells in the human body can be synthesized using biodegradable dielectric materials considering the results of dielectrophoresis of interior human cells.

Acknowledgments

The authors are grateful to the Laboratory of Advanced Research for Polymeric Material(LARPM), Govt of India for providing the facility for fabrication of composite materials using injection molding.

References

1.Mein Jin Tan, Cally Owh, Pei Lin Chee, Aung Ko Ko Kyaw, Dan Kai and Xian Jun Loh,J. Mater. Chem. **C**, 4, 5531(2016).

2.Li R, Wang L, Yin L,Materials ,11(11),2108(2018)

3. Swarnalata Tripathy, Pallavi Jali, Chhatrapati Parida, Chinmay Pradhan,Chemosphere, 261,27684(2020)

4. Subhashree Patra, Sonismita Dalai, Suvendu Sahoo, Kamal Lochan Mohanta, and Chhatrapati Parida, Natl Acad Sci Lett,43**,** 283 (2020).

5. S. Patra, K.L Mohanta, and C. Parida in "International Conference on Intelligent Computing and Communication Technologies", Springer:Berlin/Heidelberg, Germany, 2019

6. Juliana Cruz, and Raul Fangueiro, Procedia Eng.,155**,** 288(2016)

7. S Patra, KL Mohanta, C Parida Modern Physics Letters B,34(1),2150009 (2020)

8.Kilic, M., Karabul, Y., Alkan, U., Yagci, O., Okutan, M., Okutan, M. and Icelli, O. Physicochem. Probl. Miner. Process, 53(1),578(2017)

9.Kodama, Y, Orlando. R, Garcia, R. H. L, Santos P. S. and Vasquez. P. A. S, Radiation Physics and Chemistry, 124,169(2016).

10. I Schwarzova, N Stevulova, E Singovszka ,and E Terpakova, IOP Conf. Ser.: Mater. Sci. Eng. , 96(1), 01208(2015)

11. CParida,S.Patra, K.L Mohanta, S. K. Dash, and S. K. S. Parashar,**AIP** Conf Proc,1832(1),040016(2017)

12.Chhatrapati parida, Sarat Kumar Dash, Chinmay Pradhan, Sarat Chandra Das; American Journal of Material science,5(1),1(2015)

13. L Hristian, M M Ostafe, LR Manea, and Leon A L ,IOP Conf. Ser.: Mater. Sci. Eng ,145(3), 032004 (2016).

14.A.Anwar, D Elfiky, AM Ramadan, and GM Hassan, Radiat. Phys. Chem., 134, 14(2017).

Figures

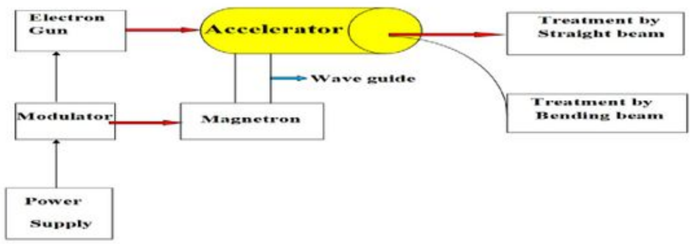

Figure 1

Schematic diagram of a medical linac

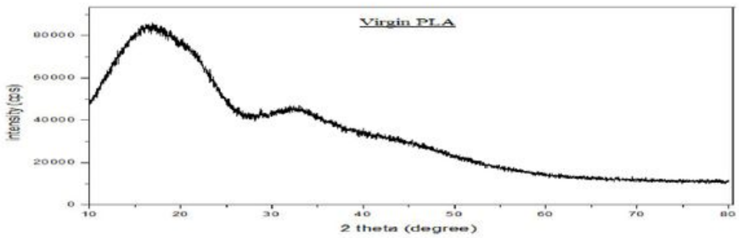

Figure 2:XRD pattern of virgin PLA

Figure 2

XRD patern of virgin PLA

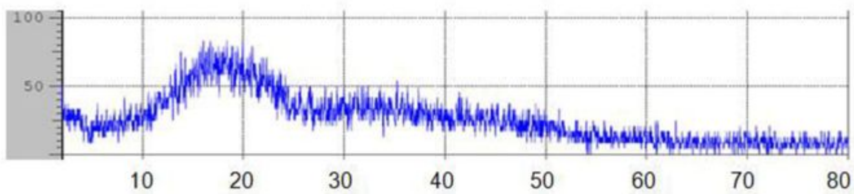

Figure 4:XRD pattern of electron beam irradiated LC fiber

Figure 3

XRD pattern of 1 Gy electron beam irradiated LC fiber composite (sample E2)

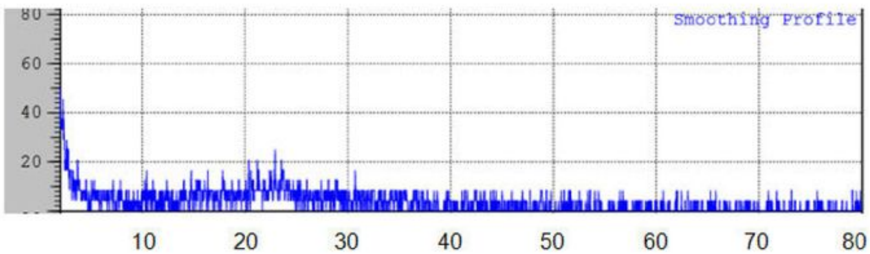

Figure 3:XRD pattern of XRD spectra of composite sample E2 (PLA with 5% fiber having electron beam irradiation dose 1.0Gy)

Figure 4

XRD pattern of electron beam irradiated LC fiber

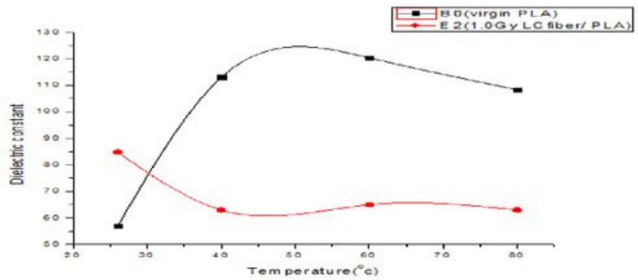

Figure 5: Variation of dielectric constant with temperature of virgin PLA and composite sample E2 at frequency 500 Hz

Figure 5

Variation of dielectric constant with temperature of virgin PLA and composite sample E2at frequency 500 Hz

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- graphicalabstract1.jpg