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Research Article

Reinforcement of Nanocellulose as Green Agent in the Electronic Applications Associated with the Composites of Polymer Matrix

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Due to their profusion, high durability, and rigidity, lesser weight and biodegradable nature nanocellulose (NC) is observed as the challenging tasks for the aspirants in making of the green composites. The continuous network of the cellulose nanoparticle connected through hydrogen bonding is happened mainly due to the reinforcing effect allocated to the mechanical reoccurrence phenomenon of the NC. When comparing with the nanocrystalline cellulose, the NC has significant convincing progress in the durability and rigidity, and the aspect ratio of the NC is higher than that of the NC crystal. The reinforcement effect of NC is the characteristic of the NC polymer interaction as well as the reinforcement effect eventualizing through stress transfer at the NC–polymer interface. Thus, the concentration of the reinforcement particle rises to the saturation level due to the frailty of the NC reinforcement constituent and due to surface compliance between the matrix and the filler. Due to its structural firmness and mechanical behaviors, the NC compounds are used in many industrial applications like tissue engineering, food packaging, and electronic applications. The stretchable electronic systems and instruments are awaiting the maximal attention due to its essential applications in certain domains, such as robotics artificial intelligence, brain control and machine interface, clinical devices, and health care electronic monitoring devices. In addition to that, when realizing the operational performance of electronic devices, the electronic instruments and systems must be physically expandable and flexible. The proposed study deems the technique of reinforcing the NC compounds as green agent in electronic applications, which has been associated with the composites of polymer matrix. The elongation could be achieved through the formulation of composition via elastomers. In addition, it is being focused on the illustration of functional soft development of materials that is inclusive of the conductive intrinsic polymers for the elongated electrodes and electrothermal conversion and vice versa, occupying the maximal area along with tactile sensing elements.

1. Introduction

Due to the environmental agitation, reduction in fossil resources, and rise in the manufacturing cost of the synthetic polymer material, many researchers are aiming to work on the biocomposite. Basically, green polymeric composites are environmentally safe, completely degenerative, and maintainable. The growth of green polymer composite would evade

Table 1: Summary of nanocellulose-essential and capable-trendy applications.

Essential nanocellulose features	Applications	Properties
Nanofiber cellulose (NCF)	Sectional automatic interiors	Maximal tensile strength
	Antireflective-coated films	Better dispersion
	Substrates to determine the activity of cellulose	Equal competence to real time cellulose substance
Nanocrystalline cellulose (NCC)	Material reinforcement in polymeric vector substance	Maximal strength
	Reinforcement of paper	Minimal toxic behavior
	Adaptive and controllable delivery of drug	Maximal aspect ratio
	Applications in biomedical imaging	
	Applications in various domains of electronics	
Nanobacterial cellulose (NBC)	Bioclinical applications	Minimal toxic to a cell membrane
	Artificial layered skin	Very pure substance
	Binder in the production of paper	Peak modulus and peak crystalline envelope
	Optically characterized opaque film	Maximal peak hydrophilicity

the disposal limitation of the plastic polymer composites. This method is proven very tedious and profitless, and it provides a bad impact on the environment [1]. Several non-renewable resources are needed for the manufacturing of the plastic component. The reinforced cellulose derivative is present in the green polymeric component due to this nature that it is capable of gaining improvement in the mechanical and electrical properties as well as the biodegradability of the polymeric substance, leading to the rise in the mechanical nature of the substance, less density, and presence of the cellulose component. Compared to the inorganic mineral, they have less bonding effect and are also best suited to produce less specific weight. With the change in the chemical nature associated with the degradation of the polymer, it might occur with the changes in the composition of the green composites [3]. Thus, leading to the drop in the structural and mechanical properties and reformation of the substance, it tends to do favor for the environment. The green polymeric components are used in many applications, such as production of the large number of products with minimal life process or the product, which are used once preexisting to dispersal [2]. The foremost step to be carried in improving the interfacial adherence between different components is that modifying the cellulose as reinforcement agent as well as the polymer matrices, leading to the augmentation of the mechanical, barrier, and the resistance nature. With the methods of dewaxing, acetylation, silane treatment, and peroxide treatment, the modification of the surface is done [4]. Therefore, to improve the mechanical strength and the reinforcement effect of the polymeric composite development of the nanocomposites is main task. Nanocomposite comprises the nanosized reinforcement element, having a dimension of 100 nm. Knowing the biological origin acquirement of the nanoelement from the various renewable resources is possible. These nanocomposites and green composites have a distinct property [5].

1.1. Nanomaterial-Multifunctional Nanocellulose. Cellulose is considered one of the most important polymers on the earth. The cellulose has the following properties that it does not have color and smell, and it is a non-toxic polymer, with high mechanical property, hydrophilicity, biocompatibility, high absorption capacity, and changeable optical appearance [6]. The cellulose does not exist in an isolated manner and is formed by the group of cellulose chain producing fibers. Due to the wider intensity of the OH bond in the structure, there exists the hydrogen bond in the structure. The morphological hierarchy is also called as the elementary fibrils, and they are combined into a larger unit called microfibrils later and are modified into a fiber structure. In the cellulose structure, various regions are formed; the highly ordered regions are called as crystalline and the disarranged order amorphous [7]. The nanocellulose (NC) structure is obtained from the extraction of the crystalline structure. Thus, the obtained nanoparticle may vary in size range having a diameter of 5–30 nm and with the length of 100–500 nm, or the length may vary from several micrometers. The nanoparticle is an elongated rod-shaped structure, they are composed of nanoparticles, and the single rod is considered as the rigid cellulosic crystal [8]. The best quantified NC is used in various applications. The lists over the trendy and essential NC applications are shown in Table 1. The various forms of the NC are opaque films, paper, hydrogels, aerogels, and sphere-shaped particles [9].

2. NC Synthesis Process

Figure 1 depicts the procedure incurred for the production of the NC. The NC is produced by the use of hydrolysis process, with the cellulose material under specific time, temperature, and agitation. The NC preparation includes the following aspects, that is, the ratio of the acid to cellulosic fiber to that of the nature of the acid [7]. The dimension of the NC is defined mainly by the origination of the cellulose; it also depends on the acid species, acid concentration, time, and temperature acquired for the hydrolysis process. Dialysis process is carried toward the distilled water in order to prevent spreading of the free acid molecules [10]. Depending on the origin of the cellulose fiber, specified hydrolysis process and separation process are performed. The rod-like nanoparticle may have size range of about 5–20 nm, and it may also vary from 100 nm to numerous micrometers, respectively [11]. The process, such as dissolving, catalyzing,

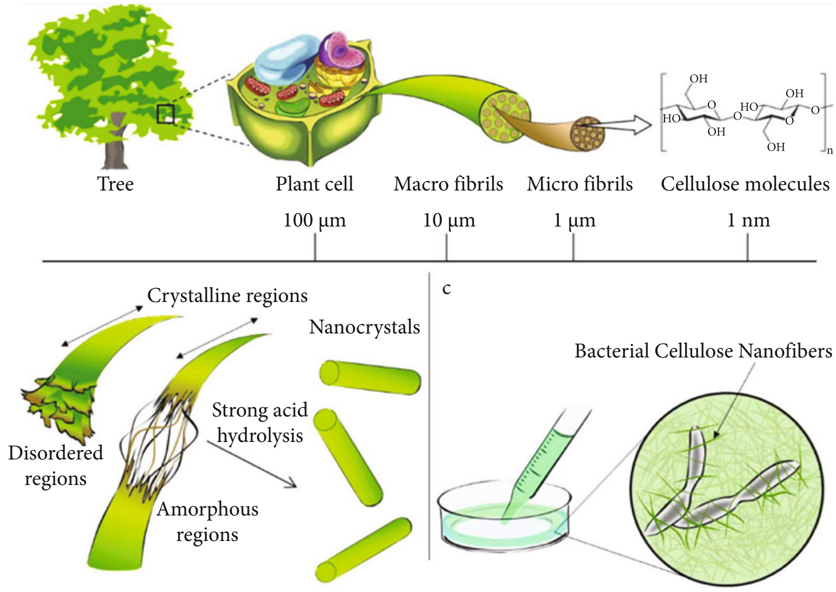

Figure 1: Traditional technique in synthesizing nanocellulose in the form of crystals [7].

and hydrolysis of cellulose, is carried by the usage of the ionic liquid. The newer version of the ionic liquid has been discovered; it is composed of the hydrogen bond donor molecule with that of the halide salts.

2.1. NC Property and Its Applications. The characteristics of the NC may differ from that of the classical material with regard to its morphology, geometric dimension, high specific surface area, alignment, orientation, and toxicity. It has the physical property merely the same as that of perfect crystals. The crystalline nature of NC provides no pattern of chain folding. The strength and the modulus are given by 7 and 140–150 GPa, respectively [12]. From the architectural representation, NC comprises the homopolysaccharide with β -1,4 anhydro-D-glucopyranose unit with varying hydroxyl groups 101 and 102. The OH groups are helpful in the formation of the hydrogen bond, and it plays a key role in the production of the semicrystalline packing and fibrillary, which reigns the objective of the cohesive component. Therefore, to perform surface functionalization, the OH groups are awarded with NC having various reactive surfaces. The NC is considered less toxic [13, 14].

3. Reinforcement in Composite System

The measurable effects are produced by adding the rigid particle with that of polymer material namely increased stiffness, depletion in the thermal expansion coefficient, and rise in the creep resistance and fracture toughness [15].

3.1. Principle and Theory. The factors that affect the mechanical behaviors of the components are its size, shape, and the aspect ratio. While determining the mechanical property of the non-spherical NC, the following parameter to be considered is its orientation with respect to its applied stress. Likewise, with the variation in the shape of the particle, the mechanical performance of the reinforced polymer gets affected [16]. This effect mainly occurs in the non-spherical shaped NC composite. Hence, several studies proved that the crystal structure of the NC produces better reinforcement comparative to that of the fiber-shaped structure [17]. The various compositions of the nanoparticle are arranged very densely compared to the monodispersed nanoparticle, thus leading to the formation of the agglomerates. Therefore, to yield larger moduli, the aggregated particle transfers large sum of load comparative to that of the primary particles [18]. NC particle is composed of multiple hydroxyl groups that stimulate both the physical and chemical relationships between the matrices and the NC, thus resulting in rise in the strength of the material. The strength and the stiffness of the material are increased by its dispersion quality.

3.2. Reinforcement of the NC in Synthetic Polymer Composites. The reinforcement effect of NC is distinguished by its crystalline and amorphous nature. The cellulose chain in the crystalline region accords to the stiffness and elasticity of the material, whereas for the amorphous region, it bestows to the plasticity and elasticity in case for the bulk material. The coefficient of the NC is obtained by the combination of the amorphous and crystalline domain. The wet NC is used to get better mechanical property of the material.

3.3. Performance of Mechanical Properties over the NC/Epoxy Composites. Epoxy components are generally malleable, and they get break down at large stress and strain. Basically, the strength and the coefficient of the material get raised by addition excess weight of about 0.3–0.6%. This growth is mainly due to the reunion of the epoxy component. The capacity of the epoxy composites is mainly dependent on the strength and the stiffness of the material. If the epoxy reunion gets poor, there arises a problem in carrying external load. There occurs an excitement between the NC and the epoxy when the bonding between them gets stronger. This, in turn, increases the coefficient of the composite. When the required amount quantity of the NC is added to the saturated volume, it ends with poor stresses and strains. Due to intermodular forces, NC usually forms bundle of aggregates having the aspect ratio less than the discrete dispersal particle. The surface functionalization is registered to increase the wettability of the NC facet. This leads to raise in interfacial interaction between the epoxy composites, whereas the salination of the NC decreases the nature of the brittleness of the composites, thus leading to betterment in the coverage of the NC; at the higher temperature, the reinforcement effect is achieved. Grafting helps in improving the dispersion of the NC in the epoxy matrix. The toughness nature is persuaded by the hyperbranched polymer structure because of the wide interaction between the composites.

3.4. Performance of Mechanical Properties over NC Polyurethane Composites. The polyurethane material basically has high flexibility and high deformation property. The mechanical behaviors of the polyurethane are affected by adding NC at when the strain at the break decreases Young's modulus and the strength of the certain levels. The coefficient of the polyurethane is grown by 253% by adding 4 wt% filler. Composites get increased, leading to the increase in the NC in the form of fiber and crystals. The strong interfacial bonding occurs with the rise in the tensile strength. When comparing with NCC to that of NCF, NCC has much higher tensile strength because of the emergence of the interconnected network. The origination of the interconnected cellulose network tends to rise in the increased filler content. The emergence of network in NC is attributed to the flexibility as well as the aspect ratio. It leads to reunion of the NCF and polyurethane as they avoid the movement of the polymer chain, which results in high strength and high numerical coefficient value. Due to the flexible nature of the NCF, there is an occurrence of several inter hydrogen bonds. The physical reunion occurred mainly due to hydrogen bonds. This tends to influence the mechanical behaviors of the composites [19]. The formation of hydrogen bond takes place with the HS and SS of the urethane group. The hydrogen bonds form when linking the polyurethane molecule and NC. With the addition of the NC to that of the NC polyurethane, the viscosity gets increased.

3.5. Performance of Mechanical Properties over NC Polyester Composites. The tensile strength of the polyester composite is between 831 and 987 MPa. This occurs with the addition of 6 wt% of the NC. Further adding NC with the polyester matrix has given rise to the tensile strength with the 10% of 4 wt% filler loading. The tensile strength increases because of the reduced volume fraction of the polyester component. When disputing the mechanical property of the composites, the acquirement of the NC interconnections bond is being obtained. These networks are capable of enacting as a load bearing component.

3.6. Mechanical Performance of NC Polyethylene Composites. With the addition of filler, the gradual increase in the strength and the Young's modulus is obtained by the polyethylene composites. Thus, this increment in these parameters says there is no variation between the NCC and the NCF. The rigidity of the NC comes up with the decrease in the elongation of breakup.

3.7. Reinforcement of NC in Biopolymeric Composites. The main phenomenon to be considered for achieving best mechanical property of the composite is good interfacial interaction and stress transfer within NC and polymer matrix. NC may best accompany with the aqua; hence, biopolymer matrix is best suited for the dispersion process. The selection of the biopolymer is one of the main aspects in this process.

3.8. Mechanical Aspect of NC Polyvinyl Alcohol Composites. The tensile strength of the polyvinyl alcohol may be 73 MPa. The tensile strength of the NC is increased by 3–5%. The mechanical property of the composite is increased by the intermolecular force between the NC and the polyvinyl alcohol. The reduction in the dispersion of the composite leads to the reduction in the tensile strength of the composite [20, 21].

3.9. Mechanical Performance of NC Gold Polyvinyl Alcohol. The existence of the polyvinyl alcohol on the base of the NC tends to increase the ductile nature of the composite. The crosslink is formed between the NC and the gold polyvinyl alcohol due to the presence of the gold particle on the NC, thus leading to the formation of the better polymer chain with increased strength and the coefficient value.

3.10. Performance of Mechanical Properties over NC Epoxy Polyvinyl Alcohol Polyacrylamide Composites. When there is less bonding between the NC, this poly acrylamide is capable of producing better tensile strength. The process of synthesizing a minimal quantum of graphene oxide has been depicted in Figure 2(a), and its formulation of nanocomposite film has been depicted in Figure 2(b). The hydrogen bonding takes place at all of these places with the presence of the NC. This hydrogen bonding takes place between the NC and the polymers. The chain mobility gets decreased due to this effect.

3.11. Mechanical Performance of Chitosan Composites. Chitosan has been used in lot of studies due to its composition; it has 1–5 wt% with the tensile property of NCF, having the young modulus of about 150% and with the composition of NCF of 12.4%. There are two factors involved in this process: one is interaction of the polymer with the nanocrystal and the other is the reinforcement effect. The interfacing of matrix and the filler is best carried with the anionic sulfate group of the NCF and the cationic group of chitosan, whereas with the composition of 12.4 wt%, NCF is not much suitable to perform the strengthening of the tensile strength. The tensile strength has been increased from 85 to 120 MPa with the gradual rise in the filler component of about 0–20 wt%. Thus, elongation at break is decreased from 20 to 6 wt%. If the component containing more than 20% of NCC, then there is a decrease in the tensile strength as well as the elongation at break point. The illustration of polyacrylamide scheme characterized with cross-linked structure has been depicted in Figure 3.

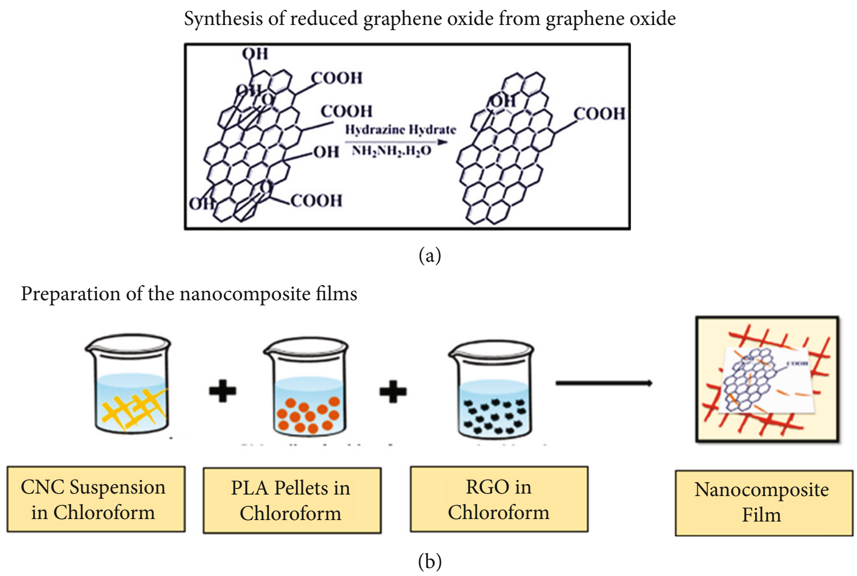

Figure 2: (a) Synthesizing of minimal quantum of graphene oxide and (b) nanocomposite film formation.

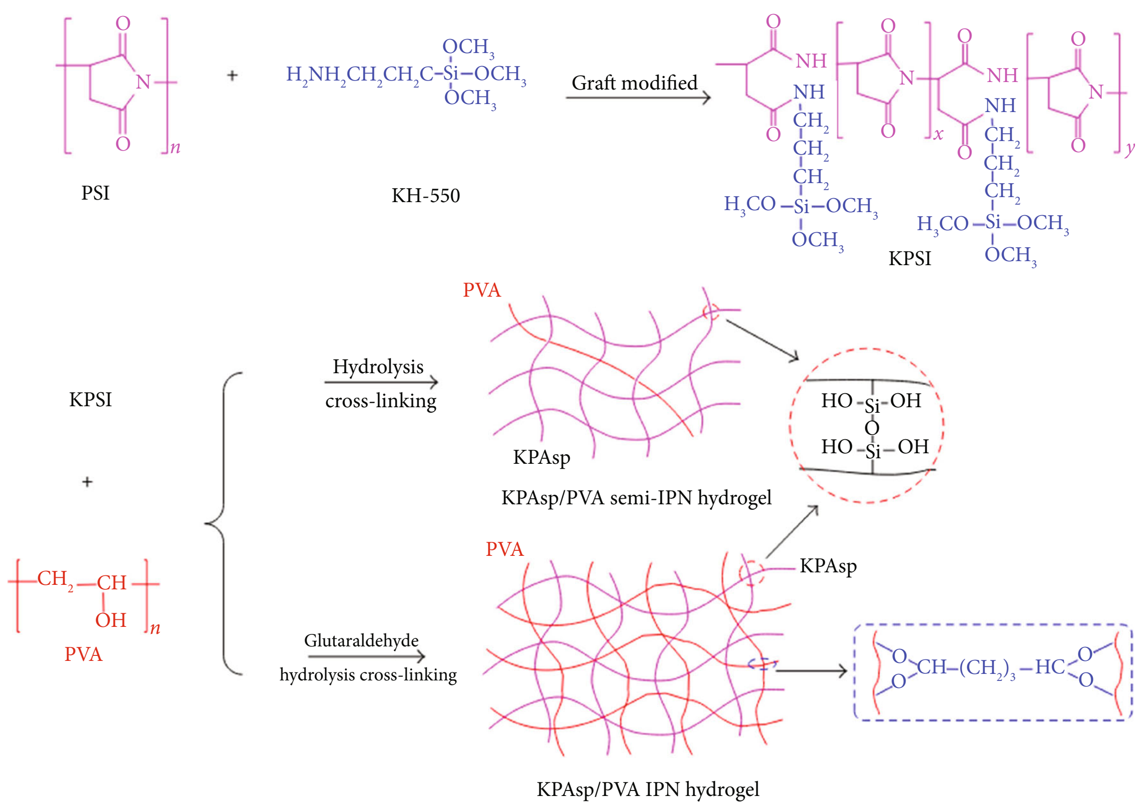

Figure 3: Illustrating the scheme of polyacrylamide characterized with cross-linked structure [20].

3.12. Mechanical Performance of NC Starch Component. Due to poor mechanical property and high hydrophilic nature, the starch-based film is not much used in several applications. The coefficient of the starch film and the tensile strength gets increased from 7.689 to 1.575 MPa, whereas the tensile strength gets increased from 7.629 to 1.515 MPa, respectively. The NCF and starch contain hydroxyl group that are capable for the formation of the hydrogen bond within the NCF chain and the starch chain.

3.13. Mechanical Performance of NC/Polycaprolactone Composites. In the room temperature, this component is mostly ductile and exhibits less elastic coefficient. In addition, NC of up to 12% leads to rise in tensile strength and

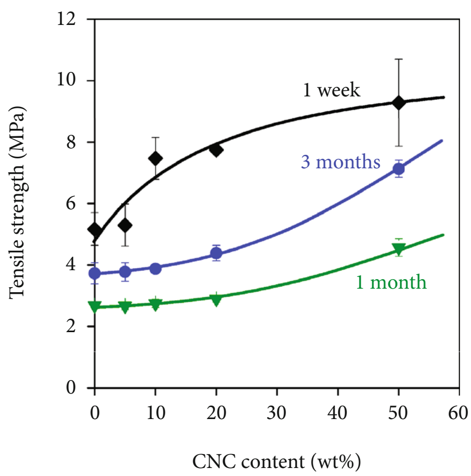

Figure 4: Characteristics over the physical and mechanical properties of CNC content across tensile strength.

reduction in strain at break [22]. This rise leads to hardness of the NC. The NCF and starch contain hydroxyl group that are suitable for the formation of the hydrogen bond.

3.14. Reinforcement of NC in Rubbery Composites. The stress–strain curve of NC composites exhibits similar fashion. Having less NC content, the rubbery material exhibits the non-linear behavior. The NBR chains are formed due to rigidity and highly crystalline nature. The composite material constitutes both the rubbery material and the NC. The characteristics over the physical and mechanical properties of CNC content across tensile strength have been depicted in Figure 4.

3.15. Performance Realization of Bulky Chain Natural Rubber Composites. The tensile strength of the natural rubber composites is increased by 250%, having the addition of the NC from the 3–15 phr. The rise in mechanical property is due to interaction property, reinforcement effect, and dispersion between the nitrile and the NC [23]. Likewise, with the tensile strength and the coefficient value, the tensile strength of the nitrile gets raised due to rise in the concentration of the NC of up to 15.88% kN/m. One of the essential factors that hinder the commercial degradation of nanoparticles is the non-presence of robust and quick characterization strategies for performing an effective process and quality assessment along the manufacturing loop. Particularly, this challenge is more significant for the existing industry of producing nanoparticles. In spite of its impressive NC properties, it could be modified in its technical form of production in reaching its maximum potential in its functioning. In addition, the enhancements of its tool of measurement in characterizing its capability are also one of the biggest challenges to be addressed.

3.16. Mechanical Performance of NC Butadiene Rubber. The mechanical performance of the NC butadiene rubber is similar to that of the nitrile rubber, and the tensile strength and tear strength of the butadiene are about 16.9–24.1 MPa and, thus, 43.5–65.3 MPa, respectively. The excellent interfacial bonding and the distribution are mainly due to rise in the modulus and the strength of the material. The cross-linking between the matrix and the NC is mainly due to NC and the nitrile butadiene rubber, as shown in Figure 5.

3.17. Illustration of Sensors Like Skin for Robotics. Being expandable, one of the most essential qualities of skin surface is transducing the deformations characterized under mechanical properties for movement, perception over tactile strength, and essentially manipulating the objects [24]. In addition to that, the skin could also make the sensing of humidity, temperature, and vibrations, as depicted in Figure 6. In both men and women, the detections over the sensations associated with the tactile properties are made by mechanoreceptors [25, 26]. The spatial density and the sensitivity associated with mechanoreceptors change across the whole body with the maximal performance and count being placed at the forearm and the leg, as depicted in Figure 6. In order to manufacture the materials, which are maximally sensitive under the deformations of mechanical structures, the demonstrations over the nano- and the microstructuring of various elastic composites and substances have been established. This adheres to piezo sensitivity. The most regularized form of piezo-sensitive substances is declared to be as carbon conductive inks or elastomers with which the variation in the resistivity of the material is being explored with the induced strain or pressure.

4. Results and Discussion

4.1. Potential Application. These NC composites are used in various applications, such as food, packaging, automobile, water treatment, and in the paper industry. There are various functions involved in the food packing process; one such process is to increase the food packing property. Polymer-based food packing has best result in the food packing industry, in which the foods are prevented from dust, oxygen, moisture, and microorganisms, thus leading to rise in maintaining the quality of the food. In the food packing industry, the NC is best suited for the filler application, as shown in Table 2. NC has been used as filler to increase the mechanical property during packing.

NC is a non-toxic material, and it is used in several biomedical applications. In tissue engineering and in the drug carrier, the potential of the NC plays a wide role, whereas several studies have proven to show the increase in the porosity of about 93%, bulk density of 0.02 g/cm, and absorption ratio of 3000%. NC crystal also possesses grafting property. They are also used in the electronic application. The mechanical property of the PEO is increased by the electrospinning property of the polyethylene oxide and poly lactic acid. Polyvinylidene fluoride-co-hexafluro propylene is used in segregation of the lithium ions in the batteries. In rubber industry, they are used in the reinforcement property of the NC crystals as well as the NC fiber.

4.2. Reinforcement of NC in Industrial Electronic Automation. A magnificent enhancement in the utilization of naturally

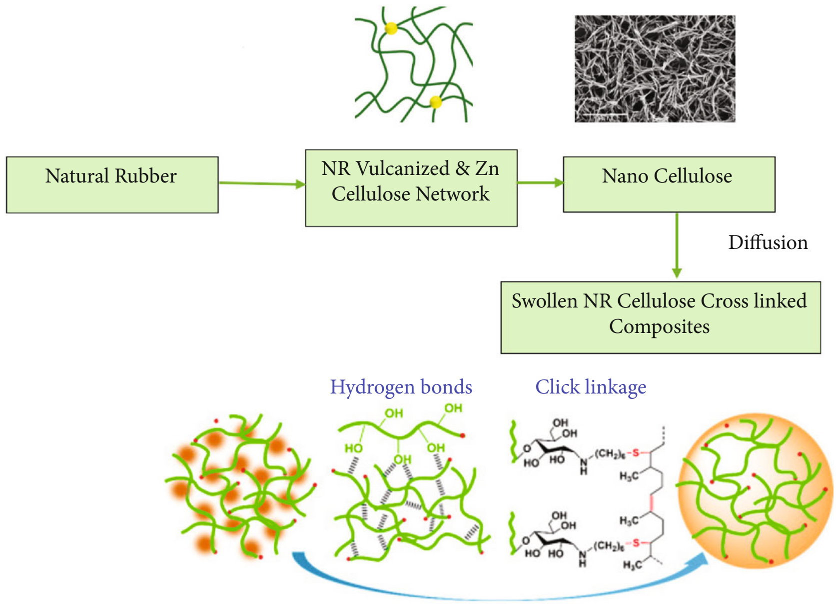

Figure 5: Illustration over the formation of dual network between rubber and ZnO.

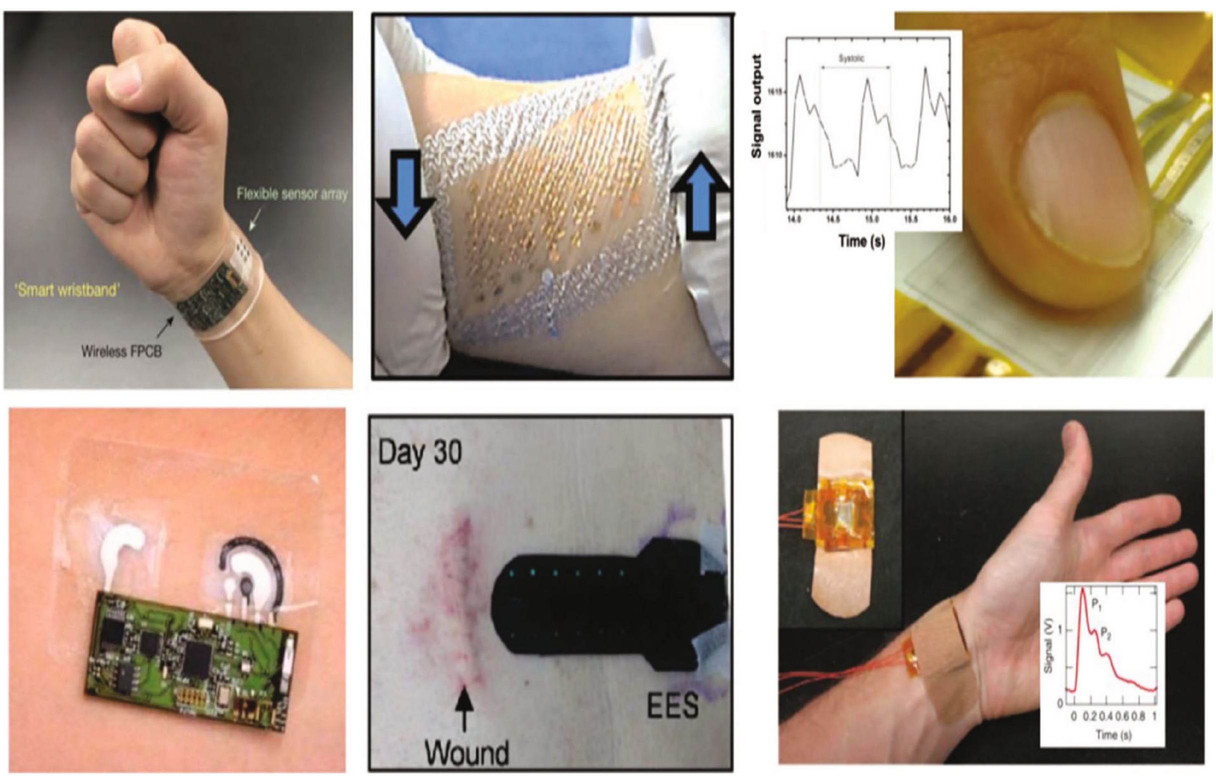

Figure 6: Illustration over the arrays of wearable integrated electronic sensors used in biohealth monitoring.

Table 2: Properties of biodegradation associated with nanocellulose system of composites.

Composites of nanocellulose	Degradable performance	Test over degradation
NCF (PLA)	The rapid initialization of degradation has been made around 5–9 weeks	ASTM D54426 at 60°C
Bacterial cellulose/starch	Cent percent degradable at 30°C	Soil
Nanocellulose/NR	After the competition of fourth week, the degradation exists over 76%	Soil

Table 3: Applications on nanocellulose polymer substrates, illustrating the electronic and mechanical domains.

S no	Usage of composite substance	Inferences
1	Digital and electronic display	Nanocellulose polymer composites have been utilized in manufacturing smart and intelligent cards, solar cells, radio spectral frequency tags, solar cells, and medical wearable sensing equipment [29].
2	Automotive mechanical parts	A substitute composite material for carbon or glass fiber nanocellulose substrates that are essentially utilized for door and window panels and glass substances
3	Packaging	The improvisation of nanocellulose polymer substrate has been realized greatly over the electronic and mechanical performance when compared to the pure polymer; it is being inferred that the permeability of O_2 content and the transmission rate of water vapor are also highly enhanced

existing polymer composites of fiber in the previous decades has been noticed, for its implication in various applications in different domains, such as construction machineries, sports machineries, automotive electronic machineries, and smart artificial intelligence machineries. Most of the countries in Europe have inculcated many efforts for enhancing the utilization of naturally developed polymer composites both in hybrid and pure nature in the components of automotive sections [27]. The major pioneers in the industrial automation also been developed in utilizing these nanopolymer composites for the non-structural and the structural elements in automobile applications. A major potential is being enforced on utilizing certain natural fibers such as flax, hemp, jute etc allowed to mix with glass or carbon resulting in hybrid form for the automotive electronic parts. The non-natural mixed fiber substances are being integrated with the electronic components with which its reliability of functioning is totally dependent on its internal bonding characteristics [28–29]. The common existing fiber composites, such as glass and banana, neither hybrid form of both being built with these NC structures, are implied for structuring the bumpers and other polyvinyl components in modernized vehicles. The reinforcement of polymer composites incorporating the banana fiber has been utilized for manufacturing the casings of mirror. The resins built by thermoset and hemp have been designed with complete body automotive functioning under certain electronics mode, and this is incorporated by Henry Ford. In addition to that, the electronic parts associated with the inserts and the door panels have been built with hybrid form of hemp–kenaf–wood composite mixtures. The reinforcement of sisal fibers within the poxy vector is being utilized for manufacturing cylinders for different electronic automotive applications. Table 3 depicts the applications on NC polymer substrates, illustrating the electronic and mechanical domains.

5. Conclusion

NC is characterized by the following properties, such as the crystalline and amorphous property. Depending on its size, the NC has better surface area, better dispersion and wettability, and increased interfacial bonding ability. The hydrophilicity may occur due to surplus quantity of the hydrogen group, thus ensuring the biodegradability and green nature of the NC composites. Various works have been enacted on the synthetic and natural polymers reinforced by the NC. In this proposed study, the applications are mainly highlighted with the enhancement and utilization of NC polymer substrates in both the domains of mechanical and electronics along with the illustrations of its unique properties. This shows the advancements in its properties when its utilization has been used in hybrid form in the state of mixed composition. It demonstrates its potentiality of being different and advantageous than the conventional mixture of composite substance that has been used traditionally. Future work includes the NC usage in the environmental application, such as water spitting as photocatalyst and in biomedical application including the antioxidant and drug carrier.

Data Availability

Data supporting this research article are available from the corresponding author or first author on reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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