Performance Optimization Analysis of Carbon Nanotube Composites Based on Fuzzy Logic

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Abstract. Materials have always been a hot issue in people's eyes. With the increasing demand for materials, the performance of various carbon nanotube composites is insufficient to meet people's needs. Therefore, the performance of carbon nanotube composites based on fuzzy logic is proposed. Optimization Analysis. Firstly, the performance equivalent parameters are calculated. On this basis, the material ratio and the standard geometry are refined. Finally, the performance of the carbon nanotube composite is optimized by the fuzzy relation matrix. The experimental results show that the optimization method can effectively improve the stability, conductivity and bearing capacity of composite materials, and prove that the optimization method can improve the performance of composite materials.

Keywords: Fuzzy logic · Carbon nanotubes · Performance optimization · Composite

1 Introduction

Carbon nanotube composite material is a kind of nanocomposite material. The special structure and superior properties of carbon nanotubes have attracted the attention of many people and have become a hot research topic in nanocomposites [1]. Through the development of technology, carbon nanotube composite materials have gradually developed into various types, including: carbon nanotube-metal composite materials, carbon nanotube-ceramic composite materials, and polymer-based carbon nanotube composite materials, even so There are still some problems to be solved in the field of composite research of carbon nanotubes.

At present, relevant experts in this field have also obtained some good research results. In literature [2], flexible poly (3, 4-ethylene dioxyethiophene)/single-walled carbon nanotube (PEDOT:SWCNT) thermoelectric composites were prepared by dynamic three-phase interfacial polymerization and physical mixing. Conclusion: The content of SWCNT has great influence on the thermoelectric property of composite. The maximum power factor reaches 253.7 ± 10.4, which is one of the highest power values of polymer-based thermoelectric composite materials. In literature [3], a simple electrophoretic deposition method was proposed to deposit copper and carbon

S. Liu and L. Xia (Eds.): ADHIP 2020, LNICST 348, pp. 103–114, 2021.
https://doi.org/10.1007/978-3-030-67874-6_10

nanotubes on the surface of carbon fiber to improve the thermal conductivity and interfacial properties of carbon fiber reinforced composites. Surface morphology, crystallization property, thermal conductivity, interlaminar shear strength (ILSS) and element distribution of the composite were characterized by scanning electron microscopy (SEM), X-ray diffraction (XRD), thermal constant analysis, short-beam bending test and SEM energy dispersive X-ray diffraction (SEM - EDX). However, the above traditional methods fail to calculate the equivalent parameters of material properties and ignore the refinement of material ratio and standard geometric shape, which results in the unsatisfactory application effect.

In order to solve the defects of its performance, it is improved based on fuzzy logic. Based on multi-valued logic, fuzzy logic is used to study the science of fuzzy thinking, language form and its laws. Through this reasoning method, the performance of carbon nanotube composites can be improved, so that it can be more effectively utilized in various fields.

2 Performance Optimization Model Design of Carbon Nanotube Composites

2.1 Performance Equivalent Parameter Calculation

In order to accurately optimize the performance of carbon nanotube composites, it is necessary to calculate various properties, convert various performance into equivalent parameters, and convert some performance into intuitive data so that the performance status can be calculated by calculation. First, the various properties should be equivalently converted to reflect the conductivity, thermal conductivity, stability, and mechanical properties of the carbon nanotube composite. First, the conductivity is equivalently converted into an electromagnetic parameter, and the electromagnetic parameters are calculated. The macroscopic electromagnetic parameters characterizing the electromagnetic properties of materials have different physical quantity representations in applications without application. In the study of absorbing properties of materials, complex magnetic permeability and complex permittivity are used. The absorbing properties of materials depend on their complex permittivity and complex permeability, so accurate measurement of the electromagnetic parameters of materials is a prerequisite for material absorbing properties. At present, the measurement method of electromagnetic parameters of materials mainly uses the cavity method, and the prepared ring sample is placed in a coaxial line or a rectangular waveguide sampler, and then the C-scattering parameter of the sample to be tested is automatically detected by a microwave vector network analyzer. The measurement process is shown in Fig. 1.

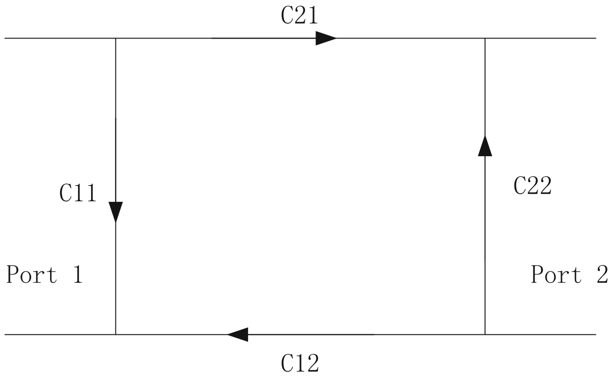

Fig. 1. Electromagnetic parameter C measurement flow chart

The meaning of the C parameters in the figure is: S11 is defined as the ratio of the reflected energy of the port 1 to the energy of the input signal of the port 1; S21 is defined as the ratio of the energy transmitted to the port 2 through the sample to be tested and the energy of the input signal of the port 1; S22 is defined as the ratio of the reflected energy of port 2 to the energy of the input signal of port 2; S12 is defined as the ratio of the energy transmitted by port 2 through the sample to be tested to the energy of port 2; according to the measured S11, S21, S12, S22 scattering parameters, using the formula to calculate electromagnetic parameters.

$$K = \frac{(C_{11}^2 - C_{21}^2) + 1}{2C_{11}} \tag{1}$$

$$T = \frac{(C_{11} + C_{21}) - (K \pm \sqrt{K^2 - 1})}{1 - (C_{11} + C_{21})(K \pm \sqrt{K^2 - 1})} \tag{2}$$

$$\frac{1}{\lambda^2} = -[\frac{1}{2\pi l} ln(\frac{1}{A_t})]^2 \tag{3}$$

$$\mu = \frac{1 + K \pm \sqrt{K^2 - 1}}{\lambda(1 - K \pm \sqrt{K^2 - 1})\sqrt{\frac{1}{\lambda_0^2} - \frac{1}{\lambda_c^2}}} \tag{4}$$

$$\varepsilon = \frac{(\frac{1}{\pi^2} + \frac{1}{\lambda_0^2})\lambda^2}{\mu} \tag{5}$$

For coaxial systems, the electromagnetic wave is a TEM wave, and the formula for calculating the complex permittivity and complex permeability is:

$$\mu = \frac{(1 + K \pm \sqrt{K^2 - 1})\lambda_0}{\lambda(1 - K \pm \sqrt{K^2 - 1})} \tag{6}$$

$$\varepsilon = \frac{(1 + K \pm \sqrt{K^2 - 1})\lambda_0}{\lambda(1 + K \pm \sqrt{K^2 - 1})} \tag{7}$$

In Eqs. 1–7, $\lambda_0, \lambda, \lambda_c$ are the wavelength of free space, the wavelength in the medium, and the cutoff wavelength in the waveguide. $1, A_t$ are the thickness of the sample and the transmission coefficient of the medium. From this, the method for solving the electromagnetic parameters can be obtained, which can be further optimized. In addition, there are other performance parameters that need to be solved and calculated. The thermal conductivity of carbon nanotube composites is calculated as:

$$k = \frac{\frac{k_{c,f}}{k_{c,ao}} + (n - 1) + (n - 1)(\frac{k_{c,f}}{k_{c,ao}} - 1)v}{\frac{k_{c,f}}{k_{c,ao}} + (n - 1) + (\frac{k_{c,f}}{k_{c,ao}} - 1)v} k_{c,ao} \tag{8}$$

Where: $k_{c,ao}$ is the composite thermal conductivity, n is the fiber shape factor, v and v_0 are the volume ratio of the composite, respectively; $k_{c,f}$ is the thermal conductivity of the thermal conductivity factor, so that the thermal conductivity can be calculated. The mechanical properties mainly refer to the compressive properties and are also important parameters for the mechanical properties of carbon nanotube composites. The mechanical properties of carbon nanotube composites were obtained by fitting the scaling law:

$$E = a\rho_c^b \tag{9}$$

Where: E is the target value for characterizing mechanical properties, and a and b are the fitting coefficients, which are the density of the carbon nanotube composite.

2.2 Refinement of the Material Ratio

When preparing the carbon nanotube composite material, the carbon nanotube as the filler can reduce the impurity doping amount, thereby improving the performance of the composite material; In the composite material in which the carbon nanotubes are combined in a loosely combined manner, the loading of adjacent carbon nanotubes is not caused by the failure of a small amount of fibers, thereby realizing material reinforcement; Carbon nanotubes have the typical stability and affinity of carbon materials, but the difference is that the outer layer of carbon nanotubes has high chemical activity and can form stable chemical bonds with matrix materials. The material thus prepared is thus enhanced in stability. According to the ratio of ferric chloride: citric acid = 1:2, nitric acid drill: citric acid = 3:2, the corresponding drugs were weighed, placed in two beakers, dissolved in a small amount of distilled water, and then placed in a water bath at 80 °C for stirring. During this process, HCl gas and gas are continuously released. The solutions in the two beakers were then mixed and then placed in a water bath at 80 °C until the liquid was a viscous gel. The obtained sol was placed in an oven at 120 °C for 3 h to obtain a dried gel. The obtained gel was calcined in a muffle furnace at 500 °C for 2 h, and the sample was naturally cooled in a furnace to obtain a drill ferrite [4].

Then, the ferrite and the carbon nanotubes of different masses are uniformly mixed, 20 mL of anhydrous alcohol is added, and then ultrasonically dispersed for 40 min. After drying, the product is uniformly mixed with paraffin, and composite samples with different mass fractions of carbon nanotubes are obtained. The mass fraction of each raw material in the sample is shown in Table 1.

Table 1. Material quality score ratio

Sample	Mass fraction		
	$FeCl_3 \cdot 6H_2O$	$Co(NO_3)_2 \cdot 6H_2O$	Citric acid
1	23.65%	46.28%	0.36%
2	27.31%	43.95%	0.56%
3	24.58%	41.97%	0.74%
4	21.97%	47.55%	0.81%

In order to obtain better results, a protective film can be applied on the surface of the prepared carbon nanotube composite material, and the coating can affect the electrical conductivity of the carbon nanotube composite material, that is, the electromagnetic parameter, that is, the absorbing coating. The absorbing properties of absorbing materials depend on two important factors: one is the impedance matching of the material to the air, and the other is the ability of the material to attenuate the propagation of electromagnetic waves, both of which depend on the electromagnetic parameters of the material. As the content of carbon nanotubes increases, the ability of the material to transmit microwaves into the coating increases rapidly, and the impedance matching of the coating with air gradually decreases. Therefore, when the content of carbon nanotubes is small, as the content of carbon nanotubes increases, the total loss of the coating increases with microwaves; when the content of carbon nanotubes in the coating increases to a certain extent, the total amount of materials to microwaves The loss reaches the maximum; continue to increase the content of carbon nanotubes in the coating, because the microwave energy entering the coating is rapidly reduced, even if the loss of the material to the microwave is enhanced, the microwave transmitted into the coating is greatly weakened, so the coating The total loss of the layer to the microwave is rapidly weakened [5]. In order to achieve the desired absorbing performance, the ratio of the coating needs to be very precise, and the index of “thin, wide, light and strong” should be achieved. In addition to selecting suitable absorbing materials, it must have a perfect structural design.

2.3 Refinement of Standard Geometric Shapes

Carbon nanotubes are a one-dimensional quantum material with a distinctive structure, also known as a bucky tube. The reason why its structure is different is that it is a coaxial tube with hexagonal carbon atoms stacked. A number of layers or dozens of layers, each layer has a fixed distance between them, the value is generally 0.34 nm, the diameter is generally 2–20 nm. Because its structure is not necessarily a single hexagon, it may also contain pentagons and heptagons, so in the process of superimposition and weaving, it may appear uneven in some places, so that the carbon nanotubes are not always straight. If the pentagon is located at the top of the carbon nanotube, a carbon nanotube seal is formed. Conversely, when the heptagon appears, the nanotube is recessed, as shown in Fig. 2.

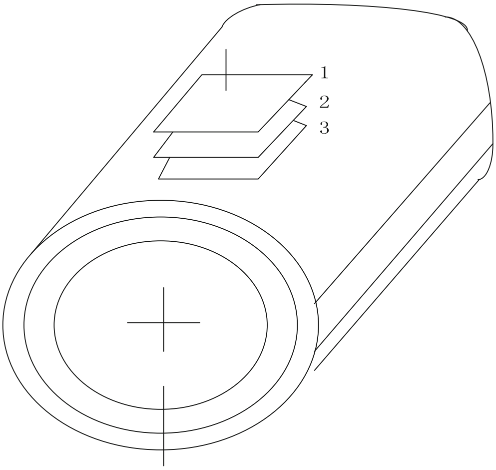

Fig. 2. Carbon nanotube geometry

Its structural speciality is also reflected in the fact that two adjacent carbon nanotubes are not connected to each other, but have a certain distance. Assuming that the displacement of the upper and lower surface layers at the interface is continuous, the lower surface of the first layer has the following displacement relationship with the upper surface of the second layer:

$$x_1 + (\frac{h_1}{2})\theta_1 = x_2 + (\frac{h_2}{2})\theta_2 \tag{10}$$

In the formula, h_1, h_2 respectively represent the thicknesses of the respective layers, x_1, x_2 respectively represent the mid-plane displacement of the respective layers, and θ_1, θ_2 respectively represent the corners of the plane normal axis and the Y-axis of the respective layers.

After specifying the movable displacement of the carbon nanotube composite material, the selection of the center of gravity in the material plays a stable role in the entire geometric structure. If the selection of the re-point is slightly biased, the stability of the structure will be affected [6]. In the actual operation, if you want to get a more accurate result, you can choose a higher center of gravity sampling, thus reducing the correction of the limited base set. In the calculation of various materials, carbon nanotubes need special attention, and its energy band calculation is different from other materials. In addition to the general precision and the setting of the base group, the structure is also considered. The difference caused. When selecting the center of gravity point, you cannot use the method of setting the center of gravity of the usual material, but should consider its unique characteristics, using only one center of gravity point in the XY direction and more center of gravity point in the Z direction. First, you must check the band structure to manually customize the center of gravity to meet the needs. The initial selection start point is (0, 0, 0), and the end point is (0, 0, 0.5), and is continuously optimized according to the experimental results. T he process of normalizing the geometry finds the structure with the lowest energy, that is, the structure that can be relatively stable, by calculating the optimized structure. In addition, in order to prevent the energy from being unreasonably accounted for in the change of the total energy, the calculated total energy error is increased, so that the error of other attribute calculations is further increased, and the energy is minimized to adjust the structure. It combines the advantages of high specific strength, specific stiffness and stability of the composite.

2.4 Fuzzy Relation Matrix Implementation Performance Optimization

The properties of carbon nanotube composites depend on various factors such as the properties, proportions and geometry of the components of the composite. After the various performance factors in the material are formulated and calculated, the fuzzy relation matrix is applied to finally optimize the performance. Let the set of factors be $A = \{a_1, a_2, \ldots a_m\}$, the composite performance set be $B = \{b_1, b_2, \ldots b_j\}$, and the influence of set A on set B:

Where R is the fuzzy relationship, each element in the set A is the amount, performance, phase geometry and other factors of each component in the composite; each element in the set B is the performance parameter of the composite, including the process performance and interface properties of the composite., mechanical properties, physical properties, stability, etc., then *ARB* means that set A has a fuzzy influence on set B [7, 8]. If there is no resistance and synergistic effect between the components in the composite, it can be called the orthogonal component factor. At this time, the composite property is written as the algebraic sum of the individual factors.

$$b_j = \sum_{d=1}^{l} g_{jd}(a_{d1}, a_{d2} \ldots, a_{di}) \tag{11}$$

Where: l is the number of components; a_{di} is the i-th factor of the d-th component. In general, composite properties can be written as a relational expression of component content [9]. The formulation test of materials is often to find out the relationship between performance and content. If the component addition amount is set to:

$$X = \{x_1, x_2, \ldots, x_j\} \tag{12}$$

Then the relationship between performance and factors can be written as:

$$b_j = \sum g_{jd}(x_d | x_d \in X) \tag{13}$$

In the formula, x_d is the amount of component d, X is the amount of component added; $g_{j,d}$ is the function of the degree of influence of the amount of component D (relative) on the properties of composite material J. Its form is determined by the properties and phase geometry of component D. That is to say, C includes all factors except the amount of component d, such as the performance and phase geometry [10–12]. The subordinate degree vector of the properties of composite material type J to the performance level is H, and the performance value is at this time:

$$b = \sum hk \Big/ \sum h \tag{14}$$

Then the influence of adding vector on J performance is aRb [13]:

$$R = \begin{Bmatrix} R_{11} \cap R_{12} \cap \ldots R_{1q} \\ R_{21} \cap R_{22} \cap \ldots R_{2q} \\ \ldots\ldots \\ R_{p1} \cap R_{p2} \cap \ldots R_{pq} \end{Bmatrix} \tag{15}$$

The degree of influence of the amount added on the performance, in the graph is to move the performance curve $+(b_{j1} - b_{j0})$, that is, the number of intervals moved $+(b_{j1} - b_{j0})$. The performance of the material is optimized by the fuzzy relation matrix to obtain the required performance and required performance level of the material.

3 Experimental Results and Analysis

In order to verify the optimization effect of the performance of the carbon nanotube composite, the experimental verification was carried out, the carbon nanotube composite material was prepared according to the optimization scheme, the sample characterization was measured and analyzed, and the phase composition of the sample was determined by X-ray diffraction method, and observed by scanning electron microscopy. The particle size and morphology of the ferrite component in the sample were measured by microwave vector network analyzer to determine the electromagnetic parameters of the sample composite in the 2–18 GHz band [9]. After the initial parameters were determined, the performance test was carried out. In order to ensure the rigor of the test, a comparative experiment was set up in the test, and the unoptimized carbon nanotube composite material was the most contrasted, and the conductivity comparison result is shown in Fig. 3.

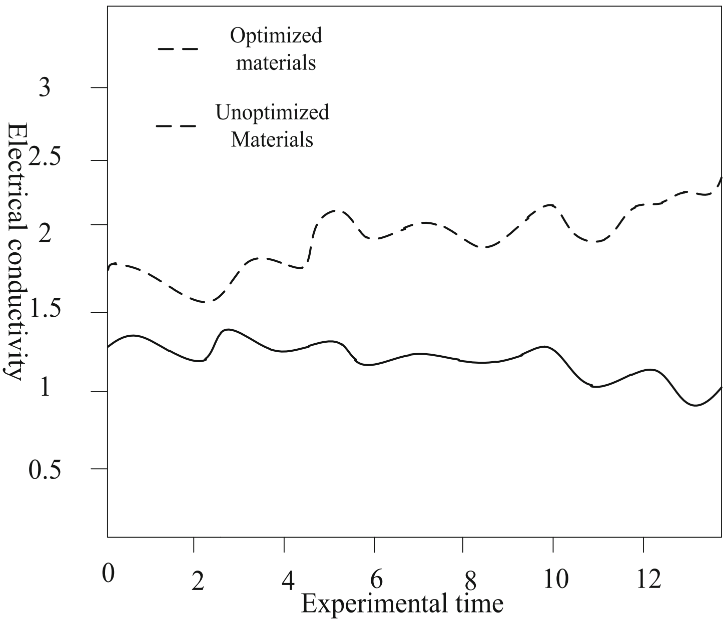

Fig. 3. Conductivity comparison results

It can be seen from the figure that the conductivity changes gradually as the material usage time increases, and the conductivity of the carbon nanotube composite material before and after optimization is between 1–2 when not in use, but with time The growth of the optimized carbon nanotube composites is on the rise, while the unoptimized carbon nanotube composites are declining. It can be seen that the optimization of the carbon nanotube composite can improve the conductivity (Fig. 4).

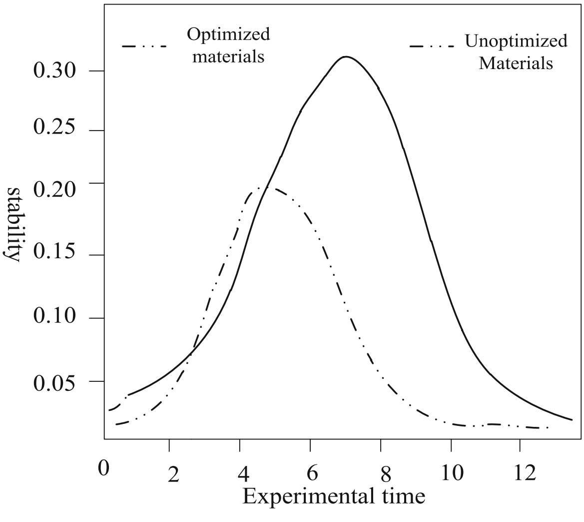

Fig. 4. Stability comparison results

After the stability analysis and comparison, it is found that the carbon nanotube composite material has its life cycle, and the stability of use in the life cycle gradually rises until the best period of life use, but in comparison, the optimized carbon nanotube composite material Stability can last longer and the stability factor is twice that of the unoptimized composite, which is enough to prove that the performance optimization scheme has the function of enhancing material stability, and the effectiveness of the optimization scheme is determined.

In order to further verify the effectiveness of the performance optimization method of carbon nanotube composites based on fuzzy logic, the aluminum carbon nanotube composites proposed in literature [2] and the metastable nickel (-carbide)/carbon nanocomposites in literature [3] were used as the experimental control group, and the bearing capacity of different materials was compared. The vertical axis of the experiment is the maximum pressure value of the material, which represents the maximum pressure capacity of the material. After reaching this value, the material will fracture. The specific experimental results are as follows:

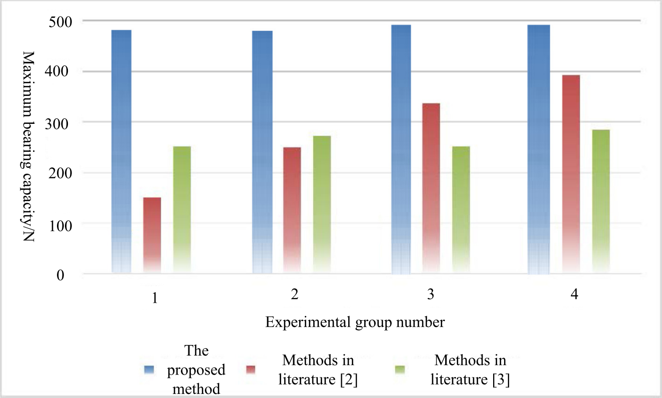

Fig. 5. The pressure properties of materials in different experimental groups were tested

According to the experimental results in Fig. 5, under the condition of constant pressure on the four groups of experimental materials, the carbon nanotube composites analyzed by methods in literature [2] and [3] broke under the pressure of 150 N to 400 N. In contrast, the performance optimization effect in this paper is more obvious. When the pressure level is nearly 500 N, the optimized carbon nanotube composite material in this paper will fracture. The experimental results show that the properties of carbon nanotube composites have been optimized effectively and the toughness has been enhanced.

4 Conclusion

The unique properties of carbon nanotubes give them many opportunities in the field of composites. Carbon nanotube composite materials have been widely used in life. However, there are still some problems with carbon nanotubes, such as the dispersion of the prepared mixture, the preparation cost and quality of the carbon nanotubes. However, the good performance exhibited by carbon nanotubes and their composites will definitely make them better applied to life.

Acknowledgments. 1. Teaching Quality and Teaching Reform Project of Guangdong Undergraduate Colleges and Universities: Construction Project of Experiment Demonstration Center (2017002);

2. Development and Management Research of “Designed Experiment” Project of Engineering Physics Experiment Course in Independent College (GDJ2016057).

References

1. Lu, X., Hu, Y., Li, W., et al.: Macroporous Carbon/nitrogen-doped carbon nanotubes/polyaniline nanocomposites and their application in supercapacitors. Electrochimica Acta **189**(12) 158–165 (2016)
2. Wusheng, F., Cunyue, G., Guangming, C.: Flexible films of poly(3,4-ethylenedioxythiophene)/carbon nanotube thermoelectric composites prepared by dynamic 3-phase interfacial electropolymerization and subsequent physical mixing. J. Mater. Chem. A **10**(6), 1039–1048 (2018)
3. Yan, F., Liu, L., Li, M., et al.: Preparation of carbon nanotube/copper/carbon fiber hierarchical composites by electrophoretic deposition for enhanced thermal conductivity and interfacial properties. J. Mater. Sci. **53**(3), 8108–8119 (2018)
4. Su, Y., Shi, B., Liao, S., et al.: Silver nanoparticles/n-doped carbon-dots nanocomposites derived from siraitia grosvenorii and its logic gate and surface-enhanced raman scattering Characteristics. ACS Sustain. Chem. Eng. **4**(3) 1728–1735 (2016)
5. Deng, W., Shen, L., Wang, X., et al.: Using carbon nanotubes-gold nanocomposites to quench energy from pinnate titanium dioxide nanorods array for signal-on photoelectrochemical aptasensing. Biosens. Bioelectron. **82**, 132–139 (2016)
6. Tang, J., Mu, B., Zong, L., et al.: Facile and green fabrication of magnetically recyclable carboxyl-functionalized attapulgite/carbon nanocomposites derived from spent bleaching earth for wastewater treatment. Chem. Eng. J. **322**, 102–114 (2017)
7. Liu, S., Bai, W., Srivastava, G., Machado, J.A.T.: Property of self-similarity between baseband and modulated signals. Mobile Netw. Appl. **25**(4), 1537–1547 (2019). https://doi.org/10.1007/s11036-019-01358-9
8. Karimi, P., Ostojastarzewski, M., Jasiuk, I.: Experimental and computational study of shielding effectiveness of polycarbonate carbon nanocomposites. J. Appl. Phys. **120**(14), 211–252 (2016)
9. Hoseini, A.H.A., Arjmand, M., Sundararaj, U., et al.: Significance of interfacial interaction and agglomerates on electrical properties of polymer-carbon nanotube nanocomposites. Mater. Des. **125**, 126–134 (2017)

10. Sanli, A., Benchirouf, A., Müller, C., et al.: Piezoresistive performance characterization of strain sensitive multi-walled carbon nanotube-epoxy nanocomposites. Sens. Actuators A **254**, 61–68 (2017)
11. Wang, Y., Zhao, X.: A theoretical model of effective electrical conductivity and piezoresistivity of carbon nanotube composites. Philos. Mag. Lett. **22**(3), 1–6 (2018)
12. Chen, H.L., Ju, S.P., Lin, C.Y., et al.: Investigation of microstructure and mechanical properties of polyvinylidene fluoride/carbon nanotube composites after electric field polarization: a molecular dynamics study. Comput. Mater. Sci. **149**(9), 217–229 (2018)
13. Awan, F.S., Fakhar, M.A., Khan, L.A., et al.: Interfacial mechanical properties of carbon nanotube-deposited carbon fiber epoxy matrix hierarchical composites[J]. Compos. Inter. **15**(5), 1–19 (2018)