Dielectric Properties of Carbon Nanotube and Their Composites Based on Ant Colony Algorithm

Ming Xu, Fei Jia and Fan Zhang
China Building Materials Academy, Beijing 100024, China

Keywords: Simulation Biology Theory, Ant Colony Algorithm, Dielectric Property Studies, Composites, Carbon Nanotube.

Abstract: The study of dielectric properties is critical in carbon nanotube and their composites, however it has an issue with erroneous performance positioning. The typical Bee colony algorithm is unable to address the inaccurate dielectric positioning issue in carbon nanotube and their composites, and the result is insufficient. With the rapid development of modern science and technology, the exploration of new materials has become a hot topic in the field of scientific research. In particular, carbon-based materials have attracted much attention due to their excellent physical and chemical properties, among which carbon nanotubes have become the focus of research due to their unique structure and superior properties. In the field of electromagnetics, the dielectric properties of materials are an important indicator to measure their response to electromagnetic waves, which is directly related to the application potential of materials in electronic devices, energy storage and conversion, etc.

1 INTRODUCTION

However, there are many challenges in the design and synthesis of carbon nanotubes and their composites, such as the precision of structural control and the complexity of the composite process (Qi and Li, et al. 2022). In this context, the bionic algorithm provides a new way to solve the above problems with its efficient and intelligent optimization strategy (Liang and Ji, et al. 2022). In this article, we will focus on the use of Ant Colony Optimization (ACO) to improve the dielectric properties of carbon nanotubes and their composites, and discuss their broad application prospects (Wu and Shao, et al. 2022).

2 RELATED CONCEPTS

2.1 The Ant Colony Algorithm is Described Mathematically

Since their discovery, carbon nanotubes have attracted attention for their excellent mechanical, electrical, and thermal properties. They are extremely high strength and flexible, and are able to withstand extreme stresses without breaking (Mei and Liu, et al. 2023). At the same time, carbon nanotubes exhibit extraordinary electrical conductivity and extremely high thermal conductivity, which make them ideal reinforcements for the preparation of high-performance composites. $tol(y_i \cdot t_{ij})$ integrated with the function to finally judge the feasibility of the study of dielectric properties, and the calculation is shown in Equation (1).

$$\lim_{x\to\infty}(y_i \cdot t_{ij}) = \frac{n!}{r!(n-r)!} y_{ij} \geq \max(t_{ij} \div 2) \tag{1}$$

Equation illustrates the evaluation of outliers among them.(2).

$$\max(t_{ij}) = \partial(t_{ij}{}^2 + 2 \cdot t_{ij}) \succ \sqrt{2}(\sum t_{ij} + 4)\mathrm{M} \tag{2}$$

Dielectric properties refer to a material's ability to store and dissipate charge in the presence of an electric field, and are usually measured by the material's dielectric constant and dielectric loss (Quan and Ji, et al. 2023). In many applications, such as capacitors, sensors, energy storage, etc., the

Xu, M., Jia, F. and Zhang, F.
Dielectric Properties of Carbon Nanotube and Their Composites Based on Ant Colony Algorithm.
DOI: 10.5220/0013536900004664

In *Proceedings of the 3rd International Conference on Futuristic Technology (INCOFT 2025) - Volume 1*, pages 140-145
ISBN: 978-989-758-763-4

dielectric properties are directly related to the performance and efficiency of the device.

Traditional methods for the preparation of carbon nanotube composites include solution mixing method, melt mixing method and in-situ polymerization method (Yong, 2022). These methods are difficult to accurately control the dispersion state and orientation of carbon nanotubes during operation, and are susceptible to the interference of multiple factors, resulting in unstable performance of the final product $F(t_i \approx 0)$ as shown by Equation (3).

$$F(d_i) = \prod \sum t_i \bigcap \xi \cdot \sqrt{2} \rightarrow \oint y_i \cdot 7 \tag{3}$$

2.2 Selection of Study of Dielectric Properties Scheme

Hypothesis II The study of dielectric properties function is $g(t_i)$, The weighting factor is w_i , The unqualified study of dielectric properties, as indicated in Equation, is thus required by the study of dielectric properties. (4).

$$g(t_i) = \ddot{x} \cdot z_i \prod F(d_i) \frac{dy}{dx} - w_i \Phi \tag{4}$$

The ant colony algorithm is an artificial intelligence algorithm proposed to simulate the behavior of ants in nature in finding food paths. Each ant releases pheromones to leave traces on the road as they search for food, and later ants choose their path based on the pheromone concentration (Geng and Zhang, et al. 2023).

$$\lim_{x \to \infty} g(t_i) + F(d_i) \le \bigcap \max(t_{ij}) \tag{5}$$

After many iterations, the shortest path has the highest concentration of pheromones, thus finding the best path from the nest to the food source. This algorithm shows strong optimization ability and robustness in solving combinatorial optimization problems (Liu and Yue, et al. 2023).

$$g(t_i) + F(d_i) \leftrightarrow \sqrt{b^2 - 4ac}\left(\sum t_{ij} + 4\right) \tag{6}$$

2.3 Analysis of Study of Dielectric Properties Scheme

In the design of carbon nanotube composites, the ant colony algorithm can be used to guide the selection of material components, the dispersion and orientation of carbon nanotubes, and other aspects of optimization (Wang and Dang, et al. 2022). The algorithm can conduct a multi-dimensional search according to the predetermined target dielectric performance parameters to find out the best synthesis conditions and process parameters, effectively improving the consistency and reliability of the final product. $No(t_i)$ shown in Equation(7).

$$No(t_i) = \frac{g(t_i) + F(d_i)}{mean(\sum t_{ij} + 4)} \sqrt{b^2 - 4ac} \tag{7}$$

Recent research cases have shown that carbon nanotube composites optimized by ant colony algorithm perform well in dielectric properties $Zh(t_i)$

$$Zh(t_i) = \lim_{x \to \infty} [\sum g(t_i) + F(d_i)] \lim_{x \to \infty} \tag{8}$$

The study of dielectric properties is $accur(t_i)$ thoroughly examined, and the threshold and index weight of the study of dielectric properties scheme are established to assure the Ant colony algorithm's correctness (Chen, 2022). The study of dielectric properties is For example, in an experiment, a composite formula with high dielectric constant and low dielectric loss was successfully found by adjusting the volatilization rate of pheromones and the search range of ants to simulate different preparation conditions (Xing and Hu, et al. 2022). The development of the material not only improves the performance of electronic devices, but also broadens its possibilities in high-frequency applications $unno(t_i)$ a

$$accur(t_i) = \frac{\min[\sum g(t_i) + F(d_i)]}{\sum g(t_i) + F(d_i)} \times 100\% \tag{9}$$

In summary, the design accuracy and performance stability of carbon nanotubes and their composites can be significantly improved with the help of the bionic intelligent algorithm, ant colony algorithm (Lu and Chen, 2022). Through this advanced algorithm, researchers can quickly locate the optimal solution in a huge experimental parameter space, which not only saves a lot of time and resources, but also promotes the application and expansion of carbon nanotubes and their composites in electronics, energy and other fields. $randon(t_i)$

$$accur(t_i) = \frac{\min[\sum g(t_i) + F(d_i)]}{\frac{1}{2}\sum g(t_i) + F(d_i)} + randon(t_i) \tag{10}$$

In the future, combined with other advanced algorithms such as deep learning, it will further promote carbon-based materials to a higher level of performance breakthroughs, and create more amazing scientific and technological achievements for mankind.

3 STUDY OF DIELECTRIC PROPERTIES OPTIMIZATION APPROACH

In the wave of modern science and technology, materials science is ushering in unprecedented development opportunities. Among them, carbon nanotubes (CNTs) have attracted much attention due to their excellent mechanical properties, electrical conductivity and thermal conductivity. As a new type of high-performance material, carbon nanotube composites have a wide range of applications, including aerospace, automotive industry, biomedicine and other fields. However, how to effectively disperse carbon nanotubes evenly in the matrix material and how to optimize their interfacial properties have always been a difficult problem for researchers to solve.

4 PRACTICAL EXAMPLES OF STUDY OF DIELECTRIC PROPERTIES

4.1 Introduction to the Study of Dielectric Properties

In this paper, we will introduce a novel optimization method that uses ant colony algorithm to significantly improve the performance of carbon nanotube composites.

Table 1: Study of dielectric properties study of dielectric properties requirements

Scope of application	Grade	Accuracy	study of dielectric properties
Electronics	I	89.35	85.37
	II	87.47	87.58
Energy storage	I	88.19	87.58
	II	88.67	85.94
Biomedical field	I	88.18	92.13
	II	93.15	87.74

The study of dielectric properties process in Table 1 is shown in Figure 1.

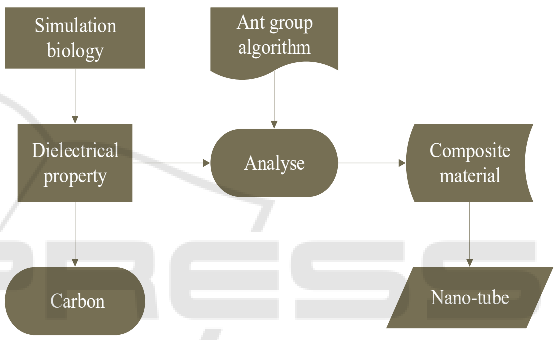

Figure 1: Analysis process of study of dielectric properties

Ant colony algorithm is a heuristic algorithm that simulates the path selection mechanism of ants in the process of foraging in nature. By mimicking the way ants release pheromones to mark paths and gradually volatilize over time, the algorithm can efficiently search for the optimal solution or approximate optimal solution. The introduction of this algorithm into the design of carbon nanotube composites means that the optimal distribution mode of carbon nanotubes in the matrix material can be predicted and guided by intelligent calculations.

4.2 Study of Dielectric Properties

First, researchers need to build a mathematical model of the carbon nanotube distribution, which should take into account the interaction of the carbon nanotubes with the matrix material, the mutual repulsion forces between the carbon nanotubes, and the expected macroscopic performance goals. Subsequently, the ant colony algorithm was used to conduct multiple rounds of iterative search, and a carbon nanotube distribution scheme was generated for each iteration, and the performance of the scheme was evaluated through an evaluation function.

Table 2: The overall situation of the study of dielectric properties scheme

Category	Random data	Reliability	Analysis rate
Electronics	94.05	89.32	89.63
Energy storage	91.51	90.04	93.18
Biomedical field	89.22	91.46	90.99
Mean	91.43	87.23	88.59
X6	83.04	86.03	84.32
		P=1.249	

4.3 Study of Dielectric Properties and Stability

By continuously iterating and adjusting the concentration of pheromones, the final algorithm converges to an optimal distribution mode that maximizes the overall performance of the composite while ensuring good dispersion of carbon nanotubes. Experiments show that the carbon nanotube composites optimized by ant colony algorithm have significant improvements in tensile strength, impact resistance and electrical properties.

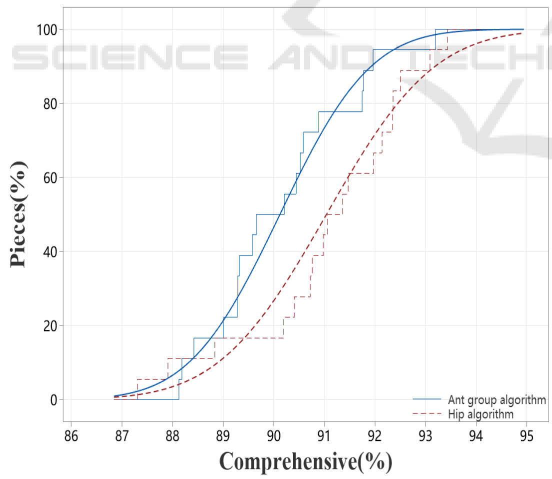

Figure 2: Evaluation model of aging performance of different algorithms

In addition, this approach offers a high degree of flexibility. By adjusting the algorithm parameters, such as the number of ants, pheromone volatilization rate, etc., it can adapt to different kinds of matrix materials and different performance requirements. For example, for applications that require higher thermal conductivity, the concentration of pheromones that help to improve the distribution pattern of the thermal conductivity path can be increased accordingly, resulting in a more accurate design.

Table 3: Compares the accuracy of several study of dielectric properties.

Algorithm	Survey data	study of dielectric properties	Magnitude of change	Error
Ant colony algorithm	89.78	86.97	90.35	89.97
Bee colony algorithm	87.33	87.67	89.71	88.32
P	88.32	90.31	88.69	88.86

It is worth mentioning that the ant colony algorithm shows a strong advantage in dealing with such complex optimization problems, which can not only find the global optimal solution, but also avoid falling into the local optimal to a certain extent, which is crucial for multivariate and multi-constraint material design problems.

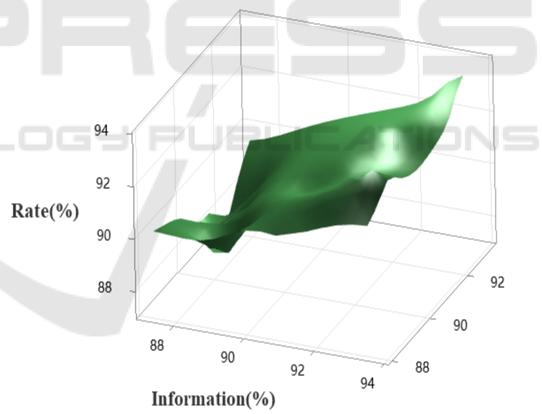

Figure 3: Study of dielectric properties of Ant colony algorithm

In summary, as an intelligent design tool, ant colony algorithm provides a new perspective and method for the research and development of carbon nanotube composites. Through the application of this biomimetic algorithm, we can not only control the material structure more precisely, but also greatly shorten the R&D cycle, reduce costs, and promote the further development and application of carbon nanotube composite technology. With the continuous improvement of algorithms and the further progress of computer technology, it is believed that more material design methods based on intelligent algorithms will be developed in the future, bringing us more powerful and efficient new materials.

4.4 Rationality of Study of Dielectric Properties

In the broad field of materials science, carbon nanotubes (CNTs) are attracting attention for their unique electrical, mechanical, and chemical properties. These tubular structures, down to the nanometer level, are considered ideal additives for reinforcing composites due to their superior strength and electrical conductivity..

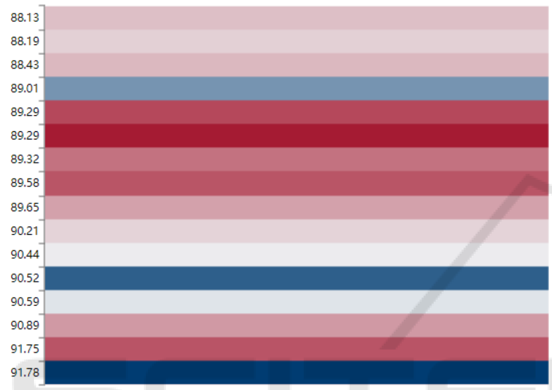

Figure 4: Evaluation model of aging performance of different algorithms

However, to realize the full potential of carbon nanotubes, the key lies in their distribution and orientation in the matrix material. This is where Ant Colony Optimization (ACO) plays an important role. In this article, we will explore in detail how ant colony algorithms can optimize the performance of carbon nanotube composites and analyze their far-reaching implications. The ant colony algorithm is derived from the simulation of ants' foraging behavior in nature. This biomimetic algorithm makes use of the concept of pheromones to find the optimal path by simulating the pheromones released by ants. Applying this algorithm to the preparation of carbon nanotube composites, scientists are actually simulating an intelligent search process to determine the optimal dispersion or arrangement of CNTs in the material.

4.5 Validity of Study of Dielectric Properties

First, ant colony algorithms can be used to guide the dispersion of CNTs in polymers or other matrix materials. By imitating the path planning of ants looking for food sources, the algorithm can effectively guide the distribution of CNTs in the matrix, avoid clumping, and ensure the uniformity and performance stability of the materials. This optimized dispersion is essential to increase the mechanical strength of materials, especially in aerospace or automotive manufacturing where precise control is required.

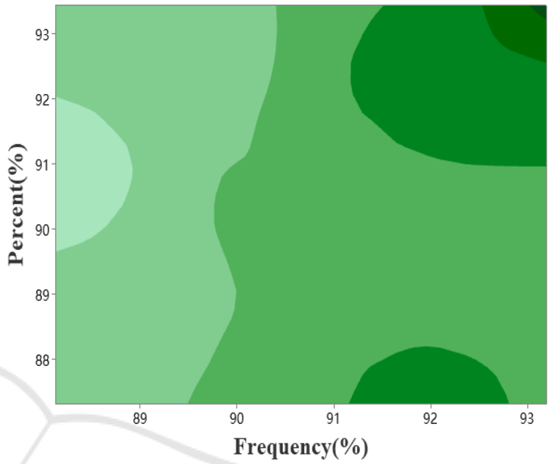

Figure 5: Study of dielectric properties of different algorithms

Further, when it comes to the orientation of carbon nanotubes, the ant colony algorithm shows its ability to adjust more finely. Orientation consistency is a key factor in improving the electrical and thermal conductivity of materials. By adjusting the algorithm parameters, the researchers can simulate a strategy similar to ants searching for the shortest path, so as to guide the CNTs to align in a specific direction, which is of great significance for the development of high-tech products such as e-skin and sensors.

Table 4: Compares the efficacy of several study of dielectric properties.

Algorithm	Survey data	study of dielectric properties	Magnitude of change	Error
Ant colony algorithm	88.37	88.50	88.73	90.11
Bee colony algorithm	89.68	91.63	90.87	87.55
P	88.28	88.44	88.97	87.48

In addition to improving macrophysical performance, the ant colony algorithm also helps to reduce production costs. Because the algorithm can efficiently guide the distribution and orientation of CNTs, it reduces the number of trial and error and raw material waste in the material preparation process, which is especially critical for large-scale production. In addition, the implementation of the algorithm does not require complex hardware support, which provides a feasible technical solution for manufacturers of all sizes.

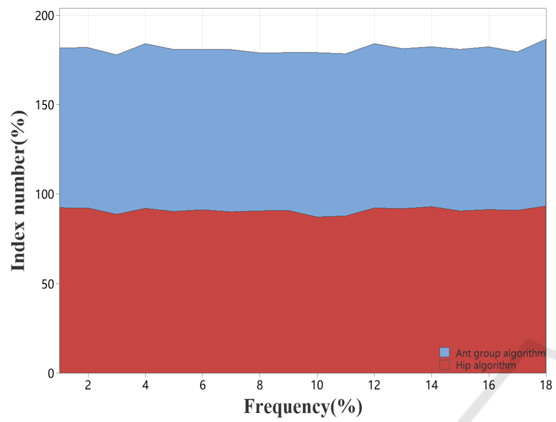

Figure 6: Ant colony algorithm study of dielectric properties

Of course, no technology can be perfect. Although ant colony algorithms have shown great potential in optimizing carbon nanotube composites, the complexity of the algorithm itself and the limitations of its applicability to different types of materials remain challenges to overcome. Researchers must constantly tune and refine algorithms to adapt to the properties and compounding requirements of different materials.

5 CONCLUSIONS

In summary, the ant colony algorithm, as an intelligent optimization tool, has shown its power in improving the performance of carbon nanotube composites. From precise control of the microstructure of materials to cost-effective production, this algorithm not only broadens the boundaries of materials science, but also opens new doors for practical applications of high-performance materials. With the advancement of science and technology and the continuous improvement of algorithms, we have reason to believe that the application of ant colony algorithms in the field of materials science will continue to show its far-reaching impact.

REFERENCES

Tang Qi, Li Shanshan, Cao Lan,&Zong Chengzhong (2022) Study on the phase structure and thermoelectric properties of one-dimensional multi walled carbon nanotubes reinforced butyl rubber/polypropylene dynamically vulcanized thermoplastic elastomer composites Rubber Technology (003), 020

Liang Yingjie, Ji Xiaoli, Yuan Haoze,&Ma Qianqian (2022) Preparation and absorption properties of silicon carbide/multi walled carbon nanotube composite materials Henan Chemical Industry, 39 (8), 4

Wu Jian, Shao Guosen, He Daihua, Chen Xiaohong, Liu Ping,&Zhang Ke (2022) Preparation and mechanical properties of carbon nanotube reinforced aluminum matrix composites Shanghai Nonferrous Metals (001), 043

Mei Jinfei, Liu Sicheng, He Yixiao, Wang Yi, Long Jin,&Hu Jian (2023) Study on the electromagnetic properties of single walled carbon nanotubes/aramid paper based composites Paper Science and Technology, 42 (2), 28-32

Quan Guipeng, Ji Chenxi, Leng Jinpeng, Xue Hongying,&Xiao Linghan (2023) Preparation and performance study of multi-component oxygenized graphene/polyether amine/carbon nanotube hierarchical structure carbon fiber composites New chemical materials

Kang Yong (2022) Research on electromagnetic shielding performance of carbon nanotube/polyvinyl alcohol composite materials Rubber and Plastic Technology and Equipment, 48 (10), 8

Geng Rong, Zhang Zhao, Niu Tianshui, Wang Yufei (2023) Research and simulation of space-based resource scheduling based on improved Bee colony algorithm Journal of Northeast University (Natural Science Edition), 44 (2), 168-176

Liu Yu, Yue Jianling,&Yan Bing (2023) A boron nitride modified silicon carbide fiber grown carbon nanotube ceramic matrix composite material and its preparation method CN116462524A

Wang Kangle, Dang Shuwen, He Fajiang,&Huang Haijun (2022) Research on 3D path planning for autonomous mobile robots based on improved Bee colony algorithm (11)

Chen Hao (2022) Preparation of nickel based single atom electrocatalysts for reducing CO2 to CO based on LDH and their structure-activity relationship study (Doctoral dissertation, Southwest University of Science and Technology)

Xing Honglong, Hu Mingqiang,&Wang Huan (2022) Aluminum/multi walled carbon nanotube composite material, preparation method and application CN201910334733.1

Lu Xiuyu,&Chen Shouli (2022) Bt@cnts Preparation and Dielectric Properties of Composite Materials by Immersion Sintering Method China Science and Technology Journal Database Industry A (8), 6