

# Review: Polymer Dielectric Nano-Composites & their Applications in Computer

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**Abstract:** *Polymer-based inorganic nanocomposites have emerged as promising materials for advanced energy storage devices, particularly supercapacitors. These materials combine the flexibility and conductivity of polymers with the high surface area and electrochemical activity of inorganic nanomaterials. This paper reviews various synthesis techniques such as in-situ polymerization, sol-gel, and hydrothermal methods, and discusses their impact on structural and electrochemical properties. The applications of these nanocomposites in supercapacitors are highlighted with emphasis on enhanced capacitance, energy density, and cycling stability.*

*Nano-composites, particularly Polymer Dielectric Nanocomposites (PDNCs), are revolutionizing material science now a days. These advanced materials combine polymers with dielectric nanoparticles, offering enhanced electrical, mechanical, and thermal properties. PDNCs have applications across diverse fields such as electronics, energy storage, and sensors, showing great promise in improving performance and efficiency in multiple industries. Polymer dielectric nanocomposites are increasingly important in electronics and energy storage due to enhanced properties like permittivity and breakdown strength. However, their design is challenging due to complex interactions between polymers and nanoparticles. This paper highlights improving polymer dielectric nanocomposites and their Applications in Computer field.*

**Keywords:** Artificial Intelligence, Polymer, Dielectric, Nano-composite

## I. INTRODUCTION

High performance Nano-composites materials have unique features. Engineering plastics and elastomers are where Nano-composites are most in demand, with an anticipated 25% annual growth rate. Their potential is so great that they are useful in many applications, from packaging to biomedical ones. The many forms of matrix Nano-composites are covered, with an emphasis on the need for these materials, their methods of manufacturing, and some recent findings regarding their structure, characteristics, and possible uses. The necessities for such materials in the future as well as other intriguing applications are projected. Applications of Nano-composites offer new technological and commercial potential for a number of industries, including aerospace, automotive, electronics, and biotechnology, due to their environmental friendliness. Polymer Dielectric Nanocomposites (PDNCs) are materials that integrate dielectric nanoparticles into polymer matrices to enhance the material's dielectric properties. This combination allows for the development of materials with improved energy storage capabilities, mechanical strength, and thermal stability [1-4].

Nano-composites have a high surface-to-volume ratio and hence have strong mechanical characteristics, making them suitable for application in the automotive and construction sectors. Nano-composites show better property enhancement over conventional composites i.e., properties such as electrical, thermal, mechanical, and barrier. They have good transparency and also reduce the property of flammability. Other uses include power tool housing, electronic covers, and so forth. In conclusion the artificial intelligence is achieving a great stability in everyday life. Artificial intelligence is a debate between society and those who support the contribution made to help humanity with the problem of hunger and above all poverty.



Polymer dielectric nanocomposites are advanced materials created by dispersing inorganic nanoparticles within a polymer matrix to enhance electrical, thermal, and mechanical properties. They are crucial for modern electronics due to their ability to combine high dielectric constants, low dielectric loss, and high breakdown strength. In computer applications, these materials are primarily used to enable **miniaturization, improved energy density in capacitors, and better heat management.**

## II. RESEARCH METHODOLOGY

**Polymer Matrices** Common polymers used in PDNCs include:

- Polyvinylidene Fluoride (PVDF): Known for its excellent piezoelectric and ferroelectric properties.
- Epoxy Resins: Used for their mechanical strength and thermal stability.
- Polyurethane: Offers flexibility and toughness.

**Dielectric Nanoparticles** Typical nanoparticles include:

- Barium Titanate ( $\text{BaTiO}_3$ ): Offers high dielectric constants and piezoelectric properties.
- Titanium Dioxide ( $\text{TiO}_2$ ): Used for its high dielectric permittivity and photocatalytic properties.
- Zinc Oxide (ZnO): Known for its varistor properties and dielectric performance.

**Fabrication Techniques**

- Solution Processing: Involves dispersing nanoparticles in a polymer solution followed by casting and curing.
- Melt Processing: Involves blending nanoparticles with molten polymer followed by extrusion or molding.
- In-Situ Polymerization: Nanoparticles are incorporated during the polymerization process.

**Dielectric Properties**

- Dielectric Constant: Enhanced by the addition of high-dielectric nanoparticles.
- Dielectric Loss: Controlled by optimizing the dispersion and interface between nanoparticles and the polymer.

**Mechanical Properties**

- Strength and Stiffness: Improved by the reinforcement effect of nanoparticles.
- Flexibility and Toughness: Maintained or enhanced depending on the polymer matrix.

**Thermal Properties**

- **Thermal Conductivity:** Can be improved by certain nanoparticles, aiding in heat dissipation.
- **Thermal Stability:** Enhanced by the thermal resistance of nanoparticles and polymer matrix.

The study of matter's properties at the Nano-scale is known as Nano-science, and it primarily focuses on the distinct, size-dependent characteristics of solid-state materials. To create materials at the Nano-scale, new synthesis processes are needed; both bottom-up and top-down methods are used. The study, manipulation, and engineering of materials, particles, and structures at the Nano-scale size are referred to as Nano-science (one millionth of a millimeter, the scale of atoms and molecules). The way molecules and atoms come together to form larger structures on the Nano-scale determines important aspects of materials, such as the electrical, optical, thermal, and mechanical properties. Furthermore, due to the importance of quantum mechanical phenomena, these features are frequently different in nanometer-sized structures than they are on the macro-scale. Carbon nanotubes are on the verge of dislodging silicon as a material for producing smaller, quicker, and more effective microchips and devices, as well as lighter, more conductive, and stronger quantum nanowires [8-11].



Nanotechnology is used for many different things and in many different fields, like computer, biology, medicine, physiology, industry, and any mechanical or chemical field. Another such area where the use of nanotechnology has recently been introduced and is consistently demonstrating as a means of maximum success and ease is artificial intelligence. The study approach is based on earlier research and expectations of practical knowledge. Our study aimed to design various Nano-composite materials that require us in the future. We work on various devices for characterization technique with Mechanical, Optical & Dielectric Properties by using XRD, SEM, TEM, AFM, FTIR, XPS (ESCA), DSC, TGA, DTA etc. Now a day there is wide range of Applications of Polymer Nano-composite such as Insulator, Packaging Industry, Energy storage material, Automotive Industry, Medical & life science field (Drug, Tumor, fracture, Joints), Film casting, Fiber spinning, Acrylic coating, Polyethylene, nylon, PVC pipes etc.

The inorganic compound barium titanate (BTO) has the chemical formula  $BaTiO_3$ . When formed as big crystals, barium titanate is clear and has a white powdery appearance. The photorefractive effect is shown by a ceramic substance that is ferroelectric, pyroelectric, and piezoelectric. It is utilised in nonlinear optics, electromechanical transducers, and capacitors.

Barium titanate is a dielectric ceramic used in capacitors, with dielectric constant values as high as 7,000. Over a narrow temperature range, values as high as 15,000 are possible; most common ceramic and polymer materials are less than 10, while others, such as titanium dioxide ( $TiO_2$ ), have values between 20 and 70. It is a piezoelectric material used in microphones and other transducers [12-25].

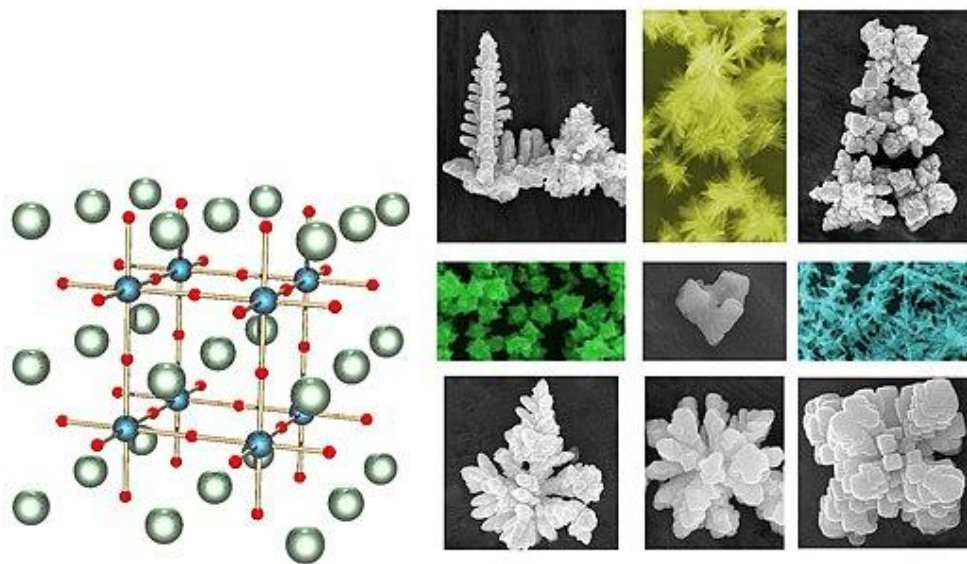


Fig. 1.1 Barium titanate structure

Here 2 nanomaterial used as Barium Titanate & ZnO, out of 2 Composite materials such as PVDF (PolyVinylDiFloride) & PMAA (poly meth acrylic acid). Any of a group of organic or synthetic compounds known as polymers is made up of macromolecules, or very large molecules, which are just multiples of simpler chemical building blocks known as monomers. Many natural and man-made materials, as well as a large portion of the components in living things, are composed of polymers.

Attributes can be developed by means of vary Nanotechnology and artificial intelligence (AI) are two of the most talked-about emerging technologies today. However, they are also the least understood in many ways. Although novel applications of either technology like AI's ability to mimic your own voice, everyday situations. Nano-materials are the only ones with the ability to perform all required tasks in their natural state. They participate in the nanotechnology process, and it is because of them that it is carried out.



### III. APPLICATIONS OF PDNC IN COMPUTER

Applications of Polymer Dielectric Nanocomposites in Computing

Polymer dielectric nanocomposites have emerged as highly promising materials for modern electronics and computing systems due to their superior dielectric, thermal, and mechanical properties. Their ability to combine lightweight polymer matrices with nanoscale fillers enables enhanced performance in compact and high-speed devices.

#### 1) Capacitors and Energy Storage Devices

These nanocomposites are extensively used in **high-density capacitors** because of their high dielectric constant and low dielectric loss. They enable capacitors to store and release electrical energy efficiently while occupying less space, making them ideal for computer chips, motherboards, and microelectronic circuits. They are also used in **embedded capacitors** within Printed Circuit Boards (PCBs) and integrated circuit (IC) packages, improving signal integrity and reducing electronic noise.

#### 2) Insulation and Protective Layers

Polymer dielectric nanocomposites serve as effective **insulating materials** in electronic devices. They are widely used as insulating layers in PCBs to prevent short circuits and electrical leakage. Additionally, they provide protective coatings for delicate components, safeguarding processors and chips against heat, moisture, and electrical discharge.

#### 3) Semiconductor Packaging

In semiconductor packaging, these materials are used to encapsulate and protect sensitive electronic chips. Their enhanced dielectric strength, moisture resistance, and thermal stability improve the reliability and lifespan of processors, memory modules, and other semiconductor devices.

#### 4) Thermal Management Systems

Nanocomposites filled with thermally conductive nanoparticles such as boron nitride or alumina are employed in **cooling systems**. They help dissipate heat generated by CPUs, GPUs, and other high-performance computing components, ensuring stable operation and preventing overheating.

#### 5) Flexible Electronics and Wearable Computing

Due to their lightweight and flexible nature, polymer dielectric nanocomposites are suitable for **foldable laptops, wearable devices, flexible displays, and smart sensors**. Their mechanical flexibility combined with excellent dielectric properties supports next-generation portable electronics.

#### 6) Memory and High-Speed Computing Devices

These materials are increasingly used in advanced **RAM modules, storage devices, and microelectronic memory systems**, where fast charge-discharge capability and stable dielectric performance are essential for higher speed and efficiency.

#### 7) Sensors and Actuators

Polymer dielectric nanocomposites are utilized in **sensors** for improved sensitivity and precision. They are also used in **piezoelectric actuators**, where accurate motion control is required in robotics, automation, and precision electronic systems.

#### 8) Telecommunications and RF Components

In telecommunications, these materials are applied in **radio frequency (RF) and microwave components**, where stable dielectric behavior at high frequencies enhances communication efficiency and signal transmission.



#### 9) **Automotive and Aerospace Electronics**

Their lightweight structure, high thermal resistance, and strong mechanical properties make them suitable for advanced electronic systems used in automotive and aerospace industries, where durability and reduced weight are essential.

#### **Key Advantages in the Computer Industry**

The growing use of polymer dielectric nanocomposites in computing offers several advantages:

- Faster electronic performance
- Better heat dissipation and thermal management
- Reduced device size and weight
- Higher energy efficiency
- Improved durability and longer component lifespan
- Reliable operation in high-speed computing systems
- Superior thermal and electrical stability
- Support for miniaturized and flexible electronic devices
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### **IV. RESULT AND DISCUSSION**

The main benefit of Nano computing is that it can significantly increase the computing power that is available to researchers. Some have expressed concern in recent years that (Moore's Law) the number of transistors per chip and, consequently, computing power, doubles over a predictable period of time, as we create ever-smaller computers. Using Nano computing is one way to solve many issues. Nano computers can perform calculations using anything from Nano to organic chemical reactions, among other novel media. However, the majority of these devices rely on complex physical systems to enable complex computational algorithms and machine learning techniques that can be used to produce novel information representations for a variety of applications. Our huge amount of data of chemical reactions useful in algorithms that have to be inputs. At present we are luckily surrounded by different kinds of machines with artificial intelligence, for example mobiles, video games, computers, air conditioners, biosensor, Electronics, Energy, Biomedicine, Environment, Food, Textile etc [31-40].

There are many Applications of Nano-composites such as:- **To make flexible batteries with high power output, Making tumors easier to diagnose and remove, Food Packaging, Automotive engine parts & fuel tanks, Thin film capacitors for Computer chips,** Flame retardants, Light emitting diodes, Photodiodes, Photovoltaic solar cells, Medical applications, Bone tissue engineering and regenerative medicine, High-voltage insulation, Corrosion protection, Infrastructure (e.g. seismic retrofit of bridges), Improved barrier properties of membranes (e.g. gas separation or filtration), Thermal barrier coatings for electronic components, Making lightweight sensor (Gas Sensor) etc.

### **V. CONCLUSION**

Polymer dielectric nanocomposites offer significant improvements in dielectric, mechanical, and thermal properties compared to pure polymers. While challenges remain in processing and cost, ongoing research and development are likely to lead to more advanced and practical applications of these materials.

Due to their low weight, high strength, high modulus, and excellent design capabilities, composite materials have taken over as the primary components of light-weight structures. Yet, traditional research approaches based on experiment, theoretical modeling, and numerical simulation meet many new attributes, design optimization, manufacturing, and processing of composite materials as the component, structure, and capability requirements become more complicated. The development of sophisticated composite materials in the future-focused engineering has been severely hindered by insufficient experimental observation, a lack of theoretical model, constrained numerical simulation, and challenging conclusion validation. Artificial intelligence employs data-driven models as opposed to the mathematical models



utilized by mechanics. It directly establishes the intricate relationships between variables from high-dimensional and high-throughput data, and then it captures the laws that are challenging to uncover.

Without using conventional simulations, we are able to predict the material properties of novel grapheme Nanocomposites thanks to a deep convolutional neural network that has been trained on a dataset of hundreds of thousands of combinations of soft and brittle materials from a finite element analysis. By adjusting the material distribution, the algorithm allows us to take physical simulations beyond the prediction of properties and maximize the fracture toughness.

Polymer dielectric nanocomposites are transforming the field of electronics and computing by enabling compact, energy-efficient, and high-performance devices. Their applications in capacitors, insulation, semiconductor packaging, thermal management, and flexible electronics make them indispensable materials for future computer technologies.

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#### **REFERENCES**

1. Zhang, Z., & Zhang, Y. (2021). Recent Advances in Artificial Intelligence and Machine Learning for Polymer Nanocomposites: Modeling and Design. *Journal of Materials Science*, 56(5), 3000-3017.
2. Liu, Y., & Zhang, M. (2019). Optimization of Dielectric Properties in Polymer Nanocomposites using Machine Learning. *Journal of Applied Polymer Science*, 136(20), 47955.
3. Miller, E., & Kumar, S. (2022). Artificial Intelligence in Advanced Polymer Nanocomposites for Energy Storage Applications. *Journal of Polymer Science*, 60(7), 547-555. K. Deshmukh, M. Basheer Ahamed, R.R. Deshmukh, S.K. Khadheer Pasha, P.R. Bhagat, K. Chidambaram, *Biopolymer Composites with High Dielectric Performance*, Interface Engineering Book Chapter 3, page 51.
4. Ajit Behara, *Advanced Materials*, Springer Science & Business Media LLC, 2022
5. *Carbon based Nanomaterials & Their Properties*, Springer Science & Business Media LLC, 2022.
6. S Sabir, *Polymer based Nanocomposites for significantly enhanced Dielectric properties & Energy storage Capacity*, Elsevier, 2018.
7. Sh. Ammar, K. Ramesh, I.A.W. Ma, Z. Farah, B. Vengadaesvaran, S. Ramesh, A.K. Arof - Studies on SiO<sub>2</sub>-hybrid polymeric nanocomposite coatings with superior corrosion protection & hydrophobicity, *Surface & Coatings Technology*, Volume 324, 15 September 2017, Pages 536-545.
8. Three Techniques Used to Produce BaTiO<sub>3</sub> Fine Powder, Natheer B. Mahmood, Emad K. Al-Shakarchi, Physics Department, College of Science, Al-Nahrain University, Baghdad, Iraq, *Journal of Modern Physics* Vol.2 No.11(2011), Article ID:8650,9 pages
9. Christian Okafor, Sunday Iwerioar, et al., Intelligent Modelling of carbonized wood silicon Dioxide filled natural Rubber composite for outer shoe sole Manufacturing, *International Journal of Lightweight & Manufacture*, 2023.
10. Xingyi Huang, Bin Sun, et al., High K Polymer nanocomposites with 1 D filler for Dielectric & Energy storage Applications, *Progress in Material Science*, 2019.
11. *Essentials in Nanoscience & NanoTechnology (Progress in Material Science)* 2016.



12. Core shell structured high K Polymer Nanocomposites for Energy storage & Dielectric Applications (Advanced Materials) 2014
13. Dielectric Polymers by Shah Mohammad (Springer Science & Business Media LLC) 2018
14. Dielectric Nanomaterials for Power Energy storage – Surface Modification & Characterization (ACS applied Nanomaterials) 2019.
15. Methods for synthesis for Nanoparticles & Fabrication of NanoComposites by Ajay Vasudev Rane, Krishnan Kenny, VK Abitha, Sabu Thomas (Elsevier BV 2018)
16. Yanbin Wang, Wenjing Jie, Chao Yang, Xianhua Wei, and Jianhua Hao - Colossal Permittivity Materials as Superior Dielectrics for diverse Applications,
17. Wen Dong,<sup>a</sup> Wanbiao Hu,<sup>a</sup> Terry J. Frankcombe,<sup>ab</sup> Dehong Chen,<sup>a</sup> Chao Zhou,<sup>c</sup> et-al, Colossal permittivity with ultralow dielectric loss in In + Ta co-doped rutile TiO<sub>2</sub>, Cite this: J. Mater. Chem. A, 2017, 5,
18. William J. Orts, Justin Shey, Syed H. Imam, Gregory M. Glenn, Mara E. Guttman, - Application of Cellulose Microfibrils in Polymer Nano-composites, Journal of Polymers and the Environment, Vol. 13, No. 4, October 2005.
19. Suelen C.M.C. Tullio, a, Ronilson V. Barbosa,<sup>b</sup> and David R. Chalcrafta , Physical and Chemical Characterization of Natural and Modified Nanoclays and their Ecotoxicity on a Freshwater Algae Species (Chlamydomonas reinhardtii) Environmental Toxicology and Chemistry—Volume 37:11 (2018) 2860–2870.
20. P.Krishnamurthy , D. Pinjari , A. Pandit , S. Mhaske, - Phase transformation of nanostructured titanium dioxide from anatase-to-rutile, via combined ultrasound assisted sol–gel technique, Ultrasonics Sonochemistry 17 (2010) 409–415.
21. K. Pandiyaraj, V. Selvarajan , R. Deshmukh, C. Gao, - Adhesive properties of polypropylene (PP) and polyethylene terephthalate (PET) film surfaces treated by DC glow discharge plasma, 032 Vacuum 83 (2009) 332-339.
22. R. Thirumdas , A. Trimukhe , R. Deshmukhb, U. Annapurea, Functional and rheological properties of cold plasma treated rice starch, [Volume 157](#) (2017) 1723-1731.
23. D.V. Godovsky – Device Applications of Polymer Nano-composites, Energy & Semiconductor Dept. University of Oldenburg 26111, Germany. Email - dmitri.godovsky@uni.-oldenburg.de
24. J. Njuguna, K. Pielichowski and S. Desai - Nanofiller-reinforced polymer Nano-composites, Polymers For Advanced Technologies, Polym. Adv. Technol. 2008; 19: 947–959, Published June 2008 in Wiley Inter Science (www.interscience.wiley.com).
25. R. Chandrakant , Holkar, Ananda J. Jadhav, Dipak V. Pinjari Naresh M. Mahamuni, Aniruddha B. Pandit, - A critical review on textile wastewater treatments: Possible approaches, [Volume 182](#), ( 2016) 351-366.
26. Wang, J., & Liu, H. (2020). Data-driven Approaches for Predicting the Dielectric Properties of Polymer Nanocomposites. Advanced Functional Materials, 30(14), 2000236
27. N. Sahooa, S. Rana b, Jae Whan Cho b, Lin Li , Siew Hwa Chana,- Polymer Nano-composites based on functionalized carbon nanotubes, journal homepage: [www.elsevier.com/locate/ppolysci](http://www.elsevier.com/locate/ppolysci), Contents lists available at Science Direct, [Progress in Polymer Science](#), Volume 35, Issue 7, Pages 837-958 (July 2010)
28. J. Sebold , S. Krohns , P. Lunkenheimer, S.G. Ebbinghaus b , S. Riegg c , A. Reller c , A. Loid Colossal dielectric constants: A common phenomenon in CaCu<sub>3</sub>Ti<sub>4</sub>O<sub>12</sub> related materials, Solid State Communications 150 (2010) 857–860.
29. Preparation of biocompatible magnetite-carboxymethyl cellulose nanocomposite: Characterization of nanocomposite by FTIR, XRD, FESEM & TEM, [Volume 131](#), 15 October 2014, Pages 55-58
30. D. C. Tiwari, Pukhrambam Dipak - PPy/TiO<sub>2</sub> (np)/CNT polymer nanocomposite material for microwave absorption, J Mater Sci: Mater Electron (2018) 29:1643–1650.
31. X.W. Wang,- Colossal dielectric properties in (Ta<sub>0.5</sub>Al<sub>0.5</sub>)xTi<sub>1-x</sub>O<sub>2</sub> ceramics - [Volume 745](#), (2018) 856-862.



32. Haiwei Du, Colossal permittivity in percolative ceramic/metal dielectric composites, *Volume 663*, 5 April 2016, Pages 848-861
33. The search for Enhanced Dielectric strength of Polymer based Dielectric – A focused based review on Polymer Nanocomposites by Danial (Journal of Applied Polymer Science 2020)
34. Thermally conductive Polymer composites for High voltage Insulation By X. Huang & P Li in 22nd International Symposium on High voltage Engineering (ISH) 2021
35. Wang, H., Li, J., & Wang, Z. (2015). Fabrication and Properties of Polymer Nanocomposites: A Review. *Advanced Materials*, 27(37), 5737-5764.
36. Theis, M. C. L., Baughman, R. H., & Lewis, R. B. (2012). Synthesis and Characterization of Dielectric Nanocomposites for Electronics. *Journal of Materials Science*, 47(16), 6187-6204.
37. Maji, P. K., Bhattacharya, T., & Kim, S. H. (2015). Dielectric Properties of Polymer Nanocomposites: A Review. *Journal of Applied Polymer Science*, 132(16).
38. Ramesh, A. M. K., Reddy, T. V. B. S., & Reddy, N. A. (2015). Mechanical and Thermal Properties of Polymer Nanocomposites: A Review. *Composites Science and Technology*, 120, 1-14.
39. Yang, S., Zhan, C., & Wang, H. (2015). Applications of Dielectric Nanocomposites in Electronics and Energy Storage. *Materials Today*, 18(6), 313-322.
40. Ong, J. P. K., Tan, H. E., & Chua, S. H. (2018). Dielectric Nanocomposites in Automotive and Aerospace Applications. *Advanced Functional Materials*, 28(38).
41. Zhang, T., Liu, L., & Liu, Y. (2015). Challenges and Future Directions in Polymer Nanocomposites. *Journal of Polymer Science: Part B: Polymer Physics*, 53(5), 627-637.
42. Hernandez, C. M. P., Selvan, M. S., & Kumar, R. D. K. S. (2016). Advances in Processing and Performance of Polymer Nanocomposites. *Materials Science and Engineering R: Reports*, 101, 1-20.
43. Sahoo, S., & Singh, S. (2020). Artificial Intelligence in Material Science: A Review of Machine Learning Applications for Polymer Nanocomposites. *Materials Today Communications*, 24, 101190.

