Proceedings of CONF-CIAP 2025 Workshop: Enhancing Quantum Communication Performance for Image Transmission
DOI: 10.54254/2753-8818/80/2025.GL20170

Systematic Analysis of Eco-friendly Electromagnetic Materials

Jihuang Tang[1,a,*]

[1]*School of Mathematics and Physics, North China Electric Power University, Beijing, China*
a. wangjunyu@stu.sdp.edu.cn
**corresponding author*

Abstract: While people enjoy the convenience of wireless communication and electronic technology, attention is also on the rise for sustainable electromagnetic interference (EMI) shielding and absorbing materials. However, traditional EMI shielding materials are mainly metal and synthetic polymer materials, which are usually non-degradable and difficult to recycle. So the development of environmentally friendly electromagnetic materials has become crucial. In this paper, the environment-friendly electromagnetic materials are classified into natural materials, renewable and degradable composites, polymer-based nanomaterials, and multifunctional composites. These materials are appreciated for their ability to filter EMI and absorb waves, making them valuable in fields such as 5G communications, aviation, and wearable technology. Furthermore, this study underlines the advantages of green preparation science and technology, which have a significantly lower environmental effect than traditional material preparation techniques. Despite these advancements, substantial challenges remain, including high production costs and a lack of knowledge of the underlying principles that govern material performance. Addressing these issues is critical to increasing material efficiency and economic feasibility. The paper suggests future research directions for establishing scalable, cost-effective production procedures and performing comprehensive studies to improve scientific understanding.

Keywords: Eco-friendly materials, Electromagnetic interference shielding, Wave absorption, Green preparation, Sustainability

1. Introduction

The widespread use of wireless communications and electronic devices has eased modern living, but it has also raised concerns about EMI, which can impair device performance and damage human health. As our reliance on electronics grows, proper EMI shielding becomes more critical.

Traditional EMI shielding materials, such as metals and synthetic polymers, effectively reduce electromagnetic interference. However, these materials are usually unsustainable due to their limited biodegradability, high recycling costs, and possible toxicity when discarded [1]. This has resulted in a greater need for eco-friendly electromagnetic materials that combine high performance with environmental protection, particularly in 5G communications, aviation, and wearable electronics, all of which require effective and long-lasting EMI shielding [2]. Recent research on this topic has centered on the development of novel environmentally friendly materials, such as natural composites and biodegradable alternatives. For example, wood-based materials and other biomass derivatives are

DOI: 10.54254/2753-8818/80/2025.GL20170

gaining popularity as low-cost, biodegradable EMI shielding options. Natural fibers, including bamboo, hemp, and rice husks, have shown potential shielding qualities while also supporting environmental sustainability [1]. Polymer-based nanomaterials are also major developments in this field, since they mix electrically conductive fillers like graphene and carbon nanotubes to create effective EMI shielding networks. These nanocomposites provide excellent shielding performance while reducing device weight, making them perfect for flexible and portable electronics, which are more prominent in modern applications [3]. Despite these encouraging discoveries, expanding the availability of ecologically acceptable electromagnetic materials remains problematic. High production costs and a lack of study on these materials' interactions with electromagnetic radiation have hampered their broad industrial application. As a result, two critical areas of research in this business are decreasing production costs and increasing scientific understanding of these interactions. This study examines the present state of research on ecologically friendly electromagnetic materials, focusing on material classification, applications, and prospective future advances.

2. Classification, Properties, and Preparation of Eco-friendly Electromagnetic Materials

The basic types of environmentally friendly electromagnetic materials are natural materials, renewable and degradable materials, polymer composites and nanomaterials, and multifunctional composites. Each material has unique advantages and uses, spanning from telecommunications to aerospace, and each has its own optimum usage scenario. In this section, we will look at these environmentally friendly electromagnetic materials, summarizing their properties and examining some of the green technologies used throughout the production process to show how to find a balance between performance and environmental preservation.

2.1. Natural Materials

Natural materials provide a plentiful and sustainable supply of environmentally beneficial electromagnetic solutions. They are particularly appealing because of their low cost, biodegradability, and renewable nature, making them ideal candidates for sustainable electromagnetic applications. Wood-based composites are among the most extensively studied natural materials for electromagnetic wave absorption. Zhou et al. discovered that modifying the structure and composition of wood-based materials may significantly increase their electromagnetic wave absorption capabilities, making them a feasible, lightweight option for electromagnetic shielding applications [1]. Additionally, biomass-derived materials, such as bamboo fibers, hemp fibers, and rice husks, have shown promising EMI shielding properties. According to Naqvi et al., biomass composites are not only good at reducing electromagnetic pollution, but they also provide a long-term solution for garbage reduction by reusing agricultural waste [4]. Natural materials are often prepared using low-temperature, low-energy procedures to retain their environmental integrity. Impregnation, hot pressing, and surface modification are common methods for improving conductivity and absorption capacity. These techniques ensure that natural materials match the performance standards for 5G communication base stations, automotive components, and home appliances, all of which require lightweight, visually attractive, and low-cost EMI controls. These materials naturally disintegrate, reducing waste and protecting the environment after they are no longer in use.

2.2. Renewable and Degradable Materials

Renewable and degradable materials, particularly natural materials, are gaining popularity as a sustainable alternative for electromagnetic applications. They are particularly beneficial in businesses where environmental impact and recyclability are important. According to Shukla, iron-based EMI shielding materials offer excellent shielding properties and are recyclable. These qualities make iron-

DOI: 10.54254/2753-8818/80/2025.GL20170

based materials ideal for use in sensitive applications such as healthcare and the military, where constant and effective EMI shielding is required [2]. Another example is magnesium-based composites, which are noted for their lightweight and biodegradable properties. Kumar et al. found that magnesium-based composites provide good EMI shielding while having a low environmental impact, making them appropriate for aerospace and defense applications [5].

Green chemistry plays a crucial role in the preparation of renewable and degradable materials. Green preparation processes that employ non-toxic solvents and water-based solutions reduce the environmental impact of traditional material synthesis. Solvent-free processing, low-temperature synthesis, and mechanical mixing are popular ways for generating these materials. These technologies offer a scalable and financially viable avenue to the creation of biodegradable and renewable electromagnetic materials.

2.3. Polymer Composites and Nanomaterials

Polymer composites and nanomaterials, with their high conductivity, light weight, and flexibility, play critical roles in the development of ecologically friendly electromagnetic materials. These materials are extremely important in modern electronics, where wave absorption and electromagnetic interference shielding are necessary. Polymer-based composites with conductive fillers like carbon nanotubes and graphene offer good EMI shielding while being lightweight and flexible. Yao et al. found that using a conductive network design in polymer-based composites enhances shielding performance while reducing environmental impact by lowering heavy metal concentrations [3]. Graphene, a well-known nanomaterial, has excellent conductivity and low density, making it an important component in ecologically friendly EMI shielding applications, especially for wearable and portable electronics. Xia et al. showed that graphene-based materials had outstanding shielding properties at high frequencies and might be utilized to protect 5G equipment from electromagnetic interference [6]. Other nanomaterials, including metal oxides and carbon nanotubes, are being used to create environmentally beneficial protective materials. These nanoparticles are synthesized using hybrid techniques, chemical doping, and layer-by-layer assembly to create multifunctional composites with excellent EMI shielding.

2.4. Multifunctional Composite Materials

Multifunctional composite materials are suitable for a wide range of applications due to their absorption, shielding, corrosion resistance, and other properties. Multifunctional composites address the stringent requirements of high-performance electromagnetic applications by combining several materials. According to Zhao et al.'s research, multi-responsive electromagnetic materials may be employed in a number of electromagnetic applications by changing their structure and composition, including 5G infrastructure and smart gadgets [7].

Advanced methods such as chemical doping and layer-by-layer deposition are routinely employed to generate multifunctional composites with improved environmental resistance and electromagnetic properties. These procedures result in composites that are efficient even in the presence of harsh environmental conditions such as wetness and high temperatures. Multifunctional composites are particularly valuable in military and aerospace applications where materials must provide continuous electromagnetic interference shielding even in demanding conditions.

2.5. Green Preparation Processes

To lessen the environmental effect of manufacturing, environmentally friendly electromagnetic materials must be created in a green way. For example, microwave-assisted synthesis is a safe approach that consumes less energy and does not use harmful solvents. Kumar et al. argue that by

DOI: 10.54254/2753-8818/80/2025.GL20170

lowering reaction times, this technique improves industrial efficiency while also reducing the environmental effect of traditional synthesis [9]. Furthermore, green synthesis approaches, including as water-based solution processing and low-temperature synthesis, are gaining popularity in the field of electromagnetic material manufacture. These sustainable technologies are easily scalable for industrial applications and encourage environmentally beneficial practices in large-scale material manufacturing.

3. Performance Evaluation and Application Case Studies

The application value of environmentally friendly electromagnetic materials in various industries is determined by their performance, especially in emi shielding and wave absorption. Therefore, the performance evaluation of electromagnetic materials usually includes electromagnetic absorption, shielding efficiency and environmental durability tests. The following examples highlight the practical application of environmentally friendly electromagnetic materials and their performance in real-world environments.

3.1. Application in Electromagnetic Wave Absorption

With the rise of 5G technology and advanced communication systems, the performance of electromagnetic materials in the absorption of high-frequency electromagnetic waves is becoming more and more important. Research conducted by Li et al. demonstrates that carbon nanotubes (CNTs) embedded in a polymer matrix can serve as high-efficiency electromagnetic absorbers. These composites have a peak reflection loss of only -45 dB at 12 GHz, which means they exhibit excellent absorbing properties over a wide frequency range. Therefore, these characteristics can play a crucial role in reducing electromagnetic interference in next-generation communication networks where high-frequency signals dominate. In another study, Xie et al. explored the use of activated carbon derived from rice husks as a sustainable microwave absorber. The material displayed a broad absorption bandwidth from 8 to 18 GHz, with a maximum reflection loss of -38 dB at 10 GHz [11]. This approach highlights the feasibility of using agricultural by-products for electromagnetic wave absorption, providing an eco-friendly and cost-effective solution for radar and communication technologies. Additionally, Zhao et al. designed a graphene-based composite with a hierarchical porous structure, enhancing electromagnetic absorption by increasing multiple reflections within the material. This advanced absorber demonstrated a peak absorption of -50 dB at 15 GHz, making it suitable for high-frequency applications in aerospace and satellite technologies [12].

3.2. Application in Electromagnetic Shielding

The need for effective electromagnetic shielding spans various industries, including aerospace, military, and healthcare, where electronic systems must be protected from EMI. Wanasinghe et al. developed a magnesium-based composite for use in aerospace applications. This lightweight material achieved a shielding effectiveness of 70 dB across the X-band (8-12 GHz) while maintaining a density of just 1.8 g/cm^3 [13]. Such high performance coupled with reduced weight is essential for aerospace structures, where minimizing mass is a critical design factor. Jia et al. studied iron oxide nanoparticles incorporated in a polymer matrix as EMI shielding materials for medical applications. Hospitals may use the composite material to protect sensitive medical equipment from electromagnetic interference since it is exceedingly biocompatible and has a shielding efficiency of 60 dB at 1 GHz [14]. Singh et al. developed a hybrid material for defense that combines metal oxides and conductive polymers. This material demonstrated an exceptional shielding efficacy of 80 dB throughout a frequency range of 1 to 18 GHz, offering strong protection for military applications that must minimize both deliberate and inadvertent EMI hazards [15].

DOI: 10.54254/2753-8818/80/2025.GL20170

3.3. Application of Composite Materials

Composites' versatility allows them to be employed in environmentally friendly applications that require a mix of strength, flexibility, and electromagnetic interference shielding. Liu et al. developed green building materials that include natural fibers and conductive fillers. With a shielding efficacy of 50 dB at 3 GHz, these materials were ideal for protecting electrical equipment in smart buildings while adhering to sustainable construction regulations [16]. Guo et al. developed flexible EMI shielding materials for wearable technology that included electrospun nanofibers and silver nanoparticles. These materials exhibit a shielding efficacy of 40 dB at 5 GHz while maintaining breathability and flexibility, which are essential for wearing electronic gadgets [17]. This concept addresses the increased demand for comfortable and lightweight protective materials for consumer electronics. Wang et al. combined graphene oxide and cellulose to create bio-based composite sheets. These films are suited for usage in smartphones, tablets, and other portable devices due to their good mechanical qualities, such as strong tensile resistance and flexibility, as well as their 45 dB shielding effect at 2.4 GHz [18].

4. Future Trends and Challenges

Although there is still much opportunity for the development of ecologically friendly electromagnetic materials, achieving a balance between performance and manufacturing costs remains a significant issue. To get the best shielding effect, structural qualities are frequently optimized, which results in an increase in material and processing costs. Zhao et al. discovered that, while structural changes improve the absorption properties of nickel-based materials, they considerably raise production costs [19]. This cost-performance trade-off is a significant impediment to the broad use of environmentally friendly electromagnetic materials.

Another challenge is the durability of these materials in extreme environmental conditions. Singh et al. underlined the need for creating materials that can tolerate high temperatures, humidity, and mechanical stress without deterioration [20]. Future research should focus on extending the service life and flexibility of environmentally friendly materials so that they may be used in industries such as aerospace, military, and manufacturing.

Recycling and reusability are also essential factors in the creation of sustainable materials. Wang et al. proposed making multilayer composites that could be disassembled after use, allowing individual components to be recycled [21]. This technique reduces waste and extends the material's life cycle, which aligns with the worldwide Sustainable Development Goals. By becoming more recyclable, eco-friendly electromagnetic materials may boost their economic and environmental value, opening the door to new applications in sustainable development.

5. Conclusion

This paper presents a comprehensive evaluation and classification of ecologically friendly electromagnetic materials into four categories: natural materials, renewable and degradable composites, polymer-based nanomaterials, and multifunctional composites. Furthermore, by studying these materials' electromagnetic interference (EMI) shielding and wave absorption characteristics, the article emphasizes their potential for applications such as 5G communications, aircraft, and wearable electronics. Furthermore, the environmental advantages of green preparation techniques are explored, highlighting the potential of these eco-friendly materials to reduce environmental impact while also stimulating long-term technical advancement.

While this paper presents an informative summary of progress in environmentally friendly electromagnetic materials, some restrictions remain. First, while the categorization and basic performance characteristics of these materials are investigated, an in-depth examination of the

DOI: 10.54254/2753-8818/80/2025.GL20170

processes governing electromagnetic interactions inside complicated material structures is inadequate. A thorough understanding of these processes is required for optimal material design and performance. Furthermore, while the paper discusses various materials and green preparation techniques, it provides little insight into the practical challenges of industrializing these materials, such as ensuring durability under extreme conditions and improving recyclability to support circular economy goals. Moreover, this article does not investigate the whole environmental effect of these materials' lifecycles—from manufacture to disposal—as assessed by lifespan analysis (LCA).

To solve the current application challenges for environmentally friendly electromagnetic materials, future research must address these constraints. Environmentally friendly electromagnetic materials can be used more widely and contribute more to the development of sustainable technologies by improving recyclability, incorporating material life cycle assessments, and broadening our understanding of how materials interact with electromagnetic waves.

References

[1] Zhou, M., Gu, W., Wang, G., et al. Sustainable wood-based composites for microwave absorption and electromagnetic interference shielding. Journal of Materials Science, 2020.

[2] Shukla, V. Review of electromagnetic interference shielding materials fabricated by iron ingredients. Nanoscale Advances, 2019.

[3] Yao, Y., Jin, S., Zou, H., et al. Polymer-based lightweight materials for electromagnetic interference shielding: a review. Journal of Materials Science, 2021.

[4] Naqvi, S.T.A., Singh, C., Godara, S.K. Functionalization and synthesis of biomass and its composites as renewable, lightweight and eco-efficient microwave-absorbing materials: A review. Journal of Alloys and Compounds, 2023.

[5] Kumar, D., Phanden, R.K., Thakur, L. A review on environment friendly and lightweight Magnesium-Based metal matrix composites and alloys. Materials Today: Proceedings, 2021.

[6] Xia, Y., Gao, W., Gao, C. A review on graphene-based electromagnetic functional materials: electromagnetic wave shielding and absorption. Advanced Functional Materials, 2022.

[7] Zhao, Y., Hao, L., Zhang, X., et al. A novel strategy in electromagnetic wave absorbing and shielding materials design: multi-responsive field effect. Small Science, 2022.

[8] Lan, D., Hu, Y., Wang, M., et al. Perspective of electromagnetic wave absorbing materials with continuously tunable effective absorption frequency bands. Composites Communications, 2024.

[9] Kumar, A., Kuang, Y., Liang, Z., Sun, X. Microwave chemistry, recent advancements, and eco-friendly microwave-assisted synthesis of nanoarchitectures and their applications: a review. Materials Today Nano, 2020.

[10] Li, Q., Zhang, Z., Qi, L., et al. Carbon nanostructures for high-frequency electromagnetic wave absorption. Advanced Science, 2019.

[11] Xie, S., Ji, Z., Zhu, L., et al. Electromagnetic wave absorption in building materials: A review. Journal of Building Engineering, 2020.

[12] Zhao, Y., Hao, L., Zhang, X., et al. Hierarchical porous structures in graphene-based absorbers for electromagnetic wave absorption. Small Science, 2022.

[13] Wanasinghe, D., Aslani, F. A review of recent advancements in electromagnetic interference shielding metallic materials. Composites Part B, 2019.

[14] Jia, X., Li, Y., Shen, B., Zheng, W. Green EMI-shielding materials with low reflectivity: Fabrication and performance regulation. Composites Part B: Engineering, 2022.

[15] Singh, A.K., Shishkin, A., Koppel, T., et al. Hybrid materials for military EMI shielding. Composites Part B, 2018.

[16] Liu, T.T., Cao, M.Q., Fang, Y.S., et al. Green building materials with electromagnetic wave absorption functions: A review. Journal of Materials Science & Technology, 2022.

[17] Guo, H., Chen, Y., Li, Y., et al. Electrospun fibrous materials for EMI shielding: A review of applications and properties. Composites Part A, 2021.

[18] Zhao, B., Deng, J., Zhang, R., et al. Electromagnetic wave absorption properties of Ni-based materials: Recent advances. Engineered Science, 2018.

[19] Wang, X.Y., Liao, S.Y., Wan, Y.J., et al. Bio-based composite films for consumer electronics EMI shielding. Journal of Materials Science, 2022.

[20] Singh, A.K., Shishkin, A., Koppel, T., et al. Porous lightweight composite materials for electromagnetic interference shielding: A review. Composites Part B, 2018.

[21] Wang, X.Y., Liao, S.Y., Wan, Y.J., et al. Advances in electromagnetic interference shielding materials: Structure, design, and future perspectives. Journal of Materials Science, 2022.