A Systematic Literature Review on Applications of Bioinspired MXenes Structures

Teshi Fernando[1#], Thisara Bandara[1#]

[1] University of Moratuwa, Katubedda, Sri Lanka
Corresponding Author 1 Teshi Fernando: teshimenasha@gmail.com
Corresponding Author 2 Thisara Bandara: thisarasanjana@gmail.com

1 Introduction

During the past few decades, material science has increasingly turned to principles of bioinspired design to develop novel materials with exceptional functionalities. MXenes which is discovered in 2011 by Naguib et al., have rapidly gathered the interest of experts in worldwide. These materials are represented by the formula $M_{n+1}X_nT_x$, where M represents a transition metal, X denotes carbon or nitrogen, and T_x stands for surface functional groups like - O, -F, and -OH. MXenes family consists of around 30 different types that can be synthesized using various techniques. MXenes have unique properties such as high electrical conductivity, excellent hydrophilicity, and large surface area [1].

The biomimicry which is also known as bio inspiration is a concept which lies at the heart of this research. Researchers aim to create new and sustainable materials by mimicking the natures intelligent structures. To enhance the properties of MXene structures, fabrication methods like Freeze Casting, Vacuum Filtration, Spray coating, In-Situ Growth, Layer-by-Layer Assembly, and electrospinning are used. These fabrication methods allow to convert bioinspiration principles into unique materials by promoting innovation in material science.

The distinct properties of MXene have led to their use in a wide range of applications. MXenes are used in biomedical applications like microneedle dressings, enzyme nano reactors, and catheter devices due to their unique electrical, optical, and mechanical properties [2]. In energy Harvesting and Storage, the high conductivity and large surface area of MXene enhance the performance[3]. Additionally, MXene-based sensors demonstrate excellent sensitivity and selectivity for detecting biomarkers and environmental pollutants. In robotics, MXenes' mechanical flexibility and sensitivity enable the creation of advanced soft robotic systems[4]. Furthermore, bioinspired MXenes structures offer innovative solutions for environmental issues, such as water treatment and pollution reduction, due to their extraordinary filtering capacities and durability. This review paper examines Mxenes' applications and discusses the challenges and future directions in the field of bioinspired MXene structure.

2 Methodology

The literature review process involved conducting a search in the Scopus database using the keywords "Bioinspired OR Biomimetic AND MXenes." This search yielded a total of 172 records. Out of these, eight were review papers, which were excluded as they do not contribute new findings. Additionally, one article was written in a language outside the primary scope of this review and was therefore omitted. The remaining research articles were then screened for relevance, specifically ensuring they addressed both bioinspiration and MXenes. Following this screening, 20 records were excluded due to irrelevance, leaving 143 papers for comprehensive analysis. The first focus of this analysis was the various fabrication methods used for MXene composites. All the metadata from these scientific publications was systematically gathered and organized using Microsoft Excel for further examination and study.

3 Results and Discussion

The screened papers were categorized into six groups based on the applications of bioinspired MXene structures: Sensing & Detectors and Robotics, Biomedical Applications, Energy Harvesting and Storage & Thermal Management, Environmental Applications, Flexible Electronics and Wearables, and other Applications (see **Fig. 1**).

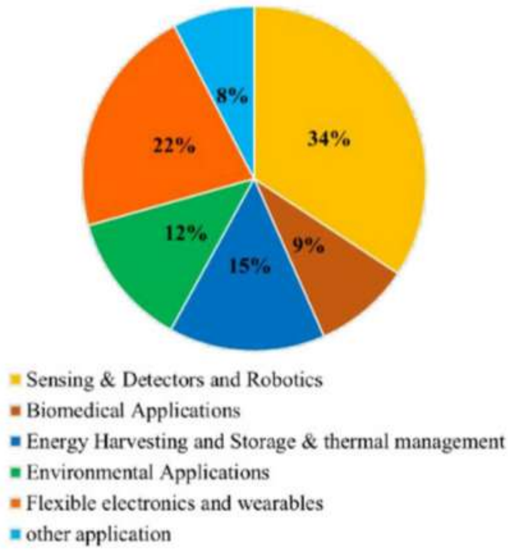

Fig. 1. Applications of Bioinspired MXene Structures.

Several bio inspirations have been adopted to develop unique MXene structures for the above-mentioned applications. Nacre's hierarchical 'brick-and-mortar' architecture provides mechanical strength and bioactivity, inspiring applications like high-performance materials and thermistor sensors. Fish skin's flexibility and mechanical robustness lead to biomimetic fish skin materials and sensitive electronic devices for underwater use. Lotus leaves, known for their superhydrophobic and self-cleaning properties, inspire coatings and tactile sensors. The porous and interconnected structure of sea sponges is mimicked in glucose detectors and robust supercapacitors. Human skin's complex sensory and mechanical properties inform the creation of electronic skins for healthcare applications. Cicada wings' anti-reflection and water-repellent characteristics inspire self-cleaning and antireflection coatings. These bioinspired approaches enable the development of MXene-based materials with advanced functionalities for diverse applications. Some of the most common bioinspiration used in developing bioinspired MXenes structures are given in **Fig. 2.** [[5], [6], [7], [8], [9].

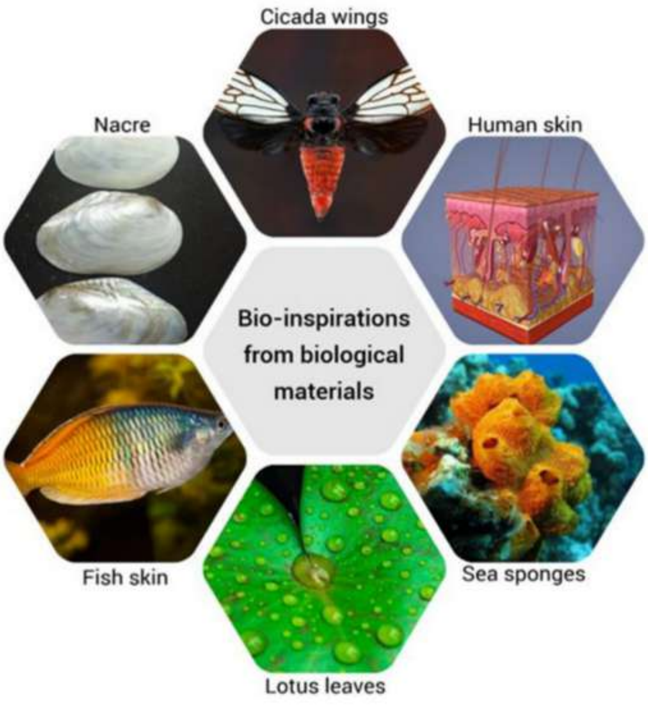

Fig. 2. Inspirations from Nature

3.1 Applications

Bioinspired MXene structures are widely used in different industries due to its unique properties and compatibility. Some of the main sectors currently utilized bioinspired MXene structures are biomedical industry, energy harvesting and storage sector, sensors & detectors, and environmental applications.

Biomedical Applications

In biomedical sector, MXene has become a popular material due to its distinctive electronic, biological, and mechanical properties. Hence, it has tended to choose as an alternative biomaterial for various equipment fabrication. Micro needle dressings are one such application which incorporated MXenes with the bioinspiration of intestinal wrinkles and villi structure due to its excellent properties such as ductility, biological friendliness, and high conductivity [10]. Another application is fabrication of a camouflaged bionic cascaded enzyme nanoreactor using the bioinspiration from the activities of enzymes in the biological systems [11].

Energy Harvesting and Storage

MXene contains extraordinary properties such as excellent strength, stiffness, electrical conductivity, and greater surface area. These exceptional features caused MXene to be utilized in energy harvesting and storage sector as well. One such example is fabrication of a photo thermal super capacitor using MXenes while employing the distinctive light capturing ability of wide leaf spiral grass during photosynthesis as the bioinspiration. The fabricated photo thermal super capacitor has an ultrahigh areal capacitance of 10.47 Fcm^{-2} and exceptional photothermal response [12].

Sensors and Detectors

Sensors & detectors are two emerging industries in the world with the rapid development of technology. To fabricate sensing and detecting equipment various types of materials are being deployed and as a recent trend MXenes and its composites are also used due to their characteristics such as high sensitivity, biological compatibility, and excellent metallic conductivity. Developing a flexible pressure sensor to monitor the pain sensation is one such application which utilized bioinspired MXenes as a material. The developed pressure sensor demonstrates higher sensitivity of 3.61 kPa^{-1} and can be used for wide pressure range over 300 kPa [13]. Additionally, MXenes and its composites have been employed in developing thermo sensitive hydrogels [14], Piezoresistive Sensors [15] , and several other applications.

Environmental Applications

Bioinspired MXenes and its composites are used in several environmental applications also. With the usage of Rod-shaped cellulose nanocrystals as the bioinspiration, a multifunctional coating has been developed to protect wood products from fire hazards and air pollution. This coating holds superior flame redundancy, remarkable smoke suppression and is a potential photocatalysis oxidation for VOCs removal as well [16]. Another application is fabricating a MXene-$Ti_3C_2T_x$ nanocarrier for pesticide delivery and plant protection. The developed application exhibits excellent photothermal conversion effect and consists of high safety which shows no side effect to the seed germination and seedling growth as well [17].

Conclusion

The attempt of conducting this systematic review of recent applications of bioinspired MXene structures is to create a path in identifying the industries and sectors which currently use MXenes in the industry level as well as in the lab scales and what are the competitive advantages which could be obtained using bioinspired MXenes as a material. Additionally, the bioinspiration which are employed in fabricating MXene based applications were also identified and presented. This paper can be utilized as a starting point to conduct research on developing new applications in various growing areas such as biomedical industry, sensors and detectors sector and energy harvesting and storage discipline. Further, to conduct literature reviews and systematic reviews on bioinspired MXenes, its applications and fabrication methods, this paper can also be utilized as an initial reference point.

Keywords: Bioinspired, Biomimetic, MXene, Applications, Review

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