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DIFFERENT BUTTERFLY WING STRUCTURES AS AN INSPIRATION FOR MILITARY APPLICATIONS

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Abstract

A variety of biophotonic species structures have been identified, as well as matches of certain types. The properties of these various morphologies are acknowledged as suitable for defining some new nanomaterials with broad applications. Military materials were found to be an especially interesting field of application. Individual structures and their application directions, as well as possible manufacturing techniques and materials, are defined.

Keywords: biomaterials, corrugation morphology, biomimetic, military applications.

1. Introduction

In nature, there are countless perfect, hidden solutions for many technological problems that are waiting to be recognized. Biomimetics is a field that deals with the application of such patterns from nature in technology and everyday life. [1] Modern times have developed the need and opportunities to find new improved materials, with extremely small dimensions and specific characteristics. This study investigates the nanostructure of biological species, butterfly wings, which are an ideal model for biomimicry due to their unique morphology. [2] Butterfly wings are also fascinating due to the diversity of structures found in different species. Figure 1 shows some examples of structures of various kinds.

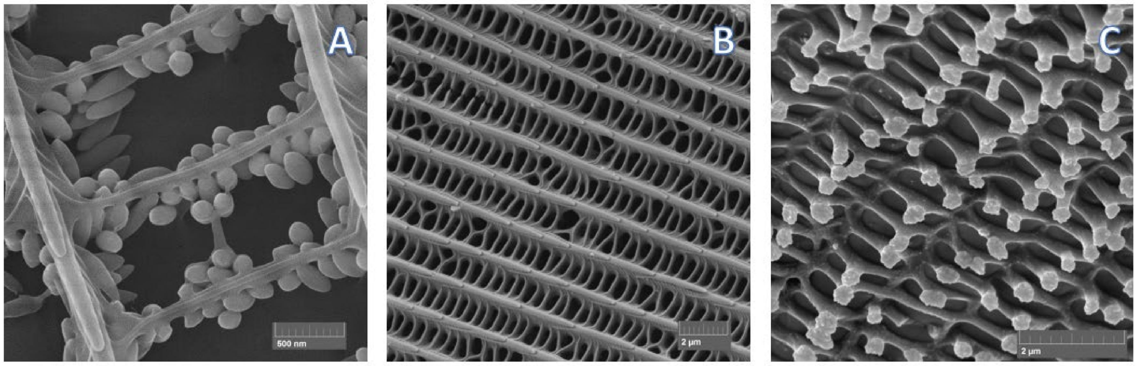

Fig. 1. SEM images of the biological structures: (A) *Pieris rapae* butterfly wing, (B) *Apatura iris* butterfly wing, and (C) *Issoria lathonia* butterfly wing.

Different types of structures were analyzed, and the technology of their production was proposed. By achieving characteristic nano dimensions within a certain material, a new type of material can be introduced. It is crucial to note that, despite their comparable chemical composition, the physical structure of butterfly wings can vary greatly. More crucially, structural differences define certain mechanical properties. Recognizing biological structures as established mechanical systems opens the door to new material development and industrial applications.

2. Materials and methods

2.1 Samples

Test samples were made by cutting different butterfly wings. The cutting was done with special tools, designed to achieve the desired size without the possibility of damaging the scales of the butterfly's wing, which consist of a large number of scales and hairs. This tool is a mold of certain diameters with a sharpened edge that rests on the sample and a kind of hammer that exerts force on the mold and in this way the sample is cut.

2.2 Scanning Electron Microscopy (SEM)

Scanning electron microscope *JEOL JSM 6610 LV (Japan)* was used for surface morphology recording. Before SEM measurements were conducted, samples were rinsed with diethyl-ether to obtain a clear surface. Rinsed samples were positioned on adhesive tape fixed to specimen tabs and then to ion sputter coated with gold.

2.3. Holography

Holography is an optical technique that registers mechanical changes at the nanoscale level by utilizing the interference of two beams. This approach is thoroughly detailed elsewhere. [3,4]

3. Results and Discussion

Among the numerous varieties of butterflies and their various structures, certain types can be distinguished. The following sections will discuss five different kinds of structures.
First and foremost, one basic structure must be presented. The butterfly *Issoria lathonia* [5] shown in Figure 2A belongs to the nanostructure usual for butterflies and shares traits with many other species. Despite their lack of specificity, natural nanostructures are always significant for the study

of various effects (thermal, optical, physicochemical, etc.) [6] applicable within a variety of micro and nano electromechanical systems (MEMS/NEMS). [7]

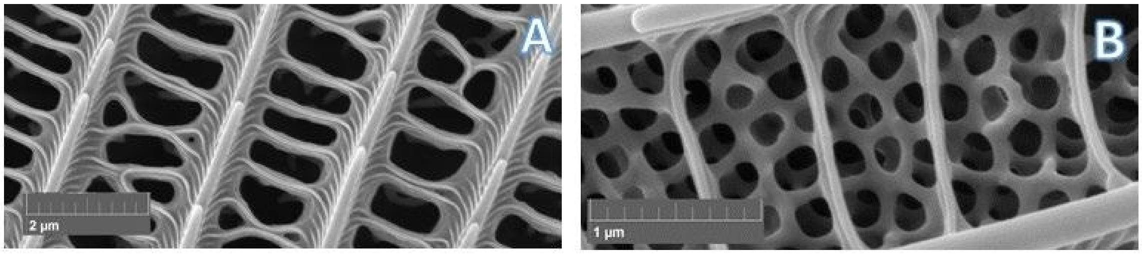

Fig. 2. SEM images: (A) *Issoria lathonia* butterfly wing and (B) *Calophrys rubi* butterfly wing.

The butterfly *Calophrys rubi* [8] is an example of a three-dimensional optical crystal structure (Figure 2B). In terms of controlling light and its interaction with various wavelengths, such optical materials have enormous potential. [9] These capabilities guarantee widespread use in a variety of light-related applications. In addition to traditional optical systems, a potential application in the military could be found in the construction of missiles in terms of fiber-optic communication needed for guidance.

The studied species of *Apatura* butterflies [10] and *Morpho* butterflies [11] belong to the herringbone type of structure (Figure 3). These structures are complex, but they also have promising material characteristics like ordering, sensitivity, and elasticity. Potential materials with this morphology would be most useful in the field of sensing, which is especially important for military uses. [12]

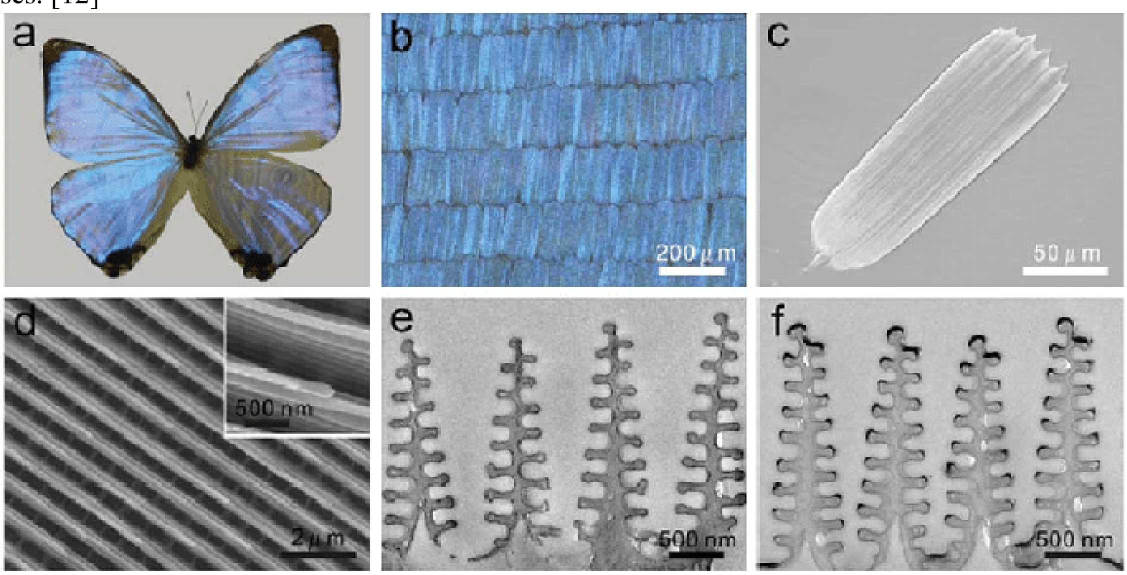

Fig. 3. Morphologies and structures of the *Morpho* butterfly wing: (a) The photo of the *Morpho sulkowskyi* butterfly; (b) Optical microscopy image of the scales on the wing surface; (c) SEM image of a single butterfly wing scale supported on a silicon substrate; (d) Top SEM view of the photonic architecture of the scale. The inset figure is a high magnification SEM showing the multilayered lamella structures; (e) TEM image of a transverse section of the scale showing ridges with lamella structures; (f) TEM image showing the selectively modified ridges. Figure 3 is taken from the ref. [11], licensed under CC BY-NC.

The butterfly *Pieris rapae* [13] is a representative of the nanogranular structure (Figure 4). Such structures are essential because they can perform the function of granular materials [14]. The idea is to take benefit of such materials' granularity while incorporating them into a consistent nanogranular material. This sort of material would offer significant benefits in terms of impact energy control and would be appropriate for armor construction [15].

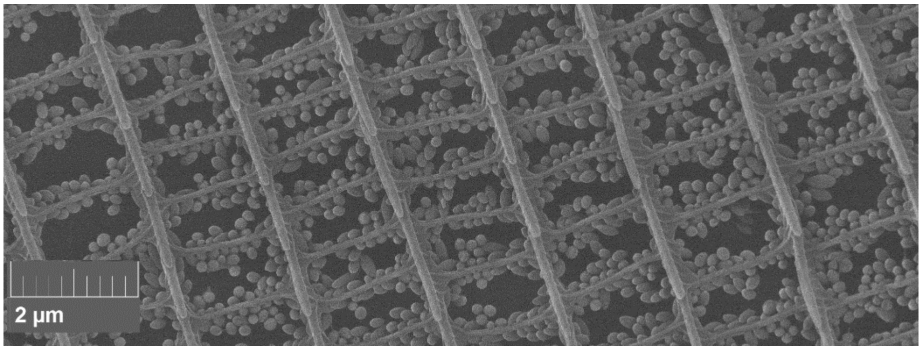

Fig. 4. SEM image of *Pieris rapae* butterfly wing.

Polyomatus [16] is a type of butterfly with a Bragg lattice type of structure (Figure 5). A changing refractive index of light characterizes a Bragg grating [17]. From a technological standpoint, these kinds of systems are most commonly used as optical components that serve as filters. The Bragg grating works by setting the filter to reflect a precisely defined range of wavelengths of emitted light while allowing others to pass through the filter unhindered. Such materials can also be used in sensing and various optical testing techniques.

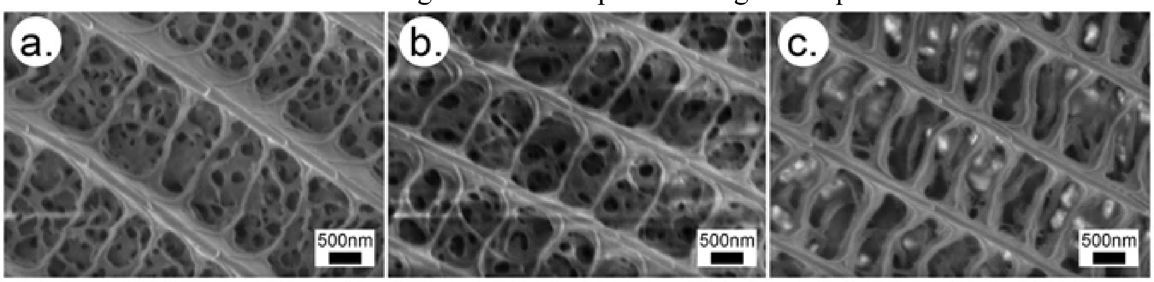

Fig. 5. SEM images of the wing scales of the female *Polyomatus*:(a) Dentate apex blue scale, (b) rounded apex blue scale, (c) brown scale. Figure 5 is taken from the ref. [16] licensed under CC BY 4.0.

For the production of certain materials, it is essential to select a material that can be processed using the chosen technology and a technology that can address the challenges presented by nanomaterials.

Silicone [18] can be considered a potential material due to properties such as temperature resistance, water resistance, and a variety of other benefits. This material can also be three-dimensionally stamped [19], which could be a perfect technology for such structures. Prior to the manufacturing process, the structure must be simplified in terms of engineering without losing its distinctive properties, and its exact dimensions must be determined. Additionally, a simplified representation of the architecture of one kind of biological structure – the structure of *Morpho* butterfly wing is provided in Figure 6.

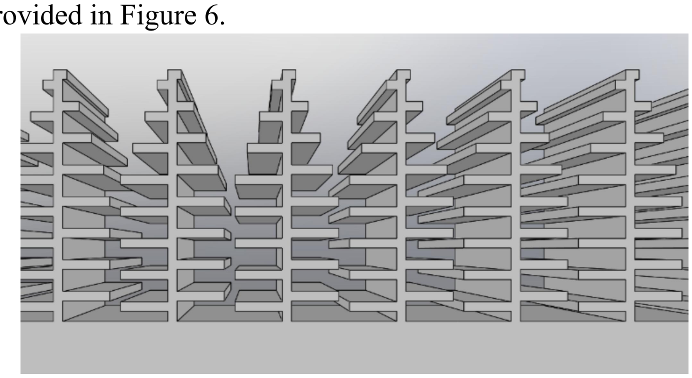

Fig. 6. simplified representation of the architecture of herringbone type of nano structure for potential application in sensor industry.

This structure was chosen after investigating the thermo-mechanical phenomenon – thermophoretic effect that occurs when electromagnetic radiation is absorbed on a piece of material, causing a temperature gradient to form on it while the mean free path of the molecules in the surrounding gas is roughly equal to the characteristic dimension of the piece of material. [20] The thermophoretic effect is based on the fact that molecules of the surrounding gas carry considerably more mechanical momentum from the warmer side of the material than the colder side, creating forces that cause the substance to move mechanically. The holographic interference method measures the conversion of the energy of invisible electromagnetic radiation into mechanical displacement of the micromechanical detecting system, so that the magnitude of the mechanical displacement is proportionate to the energy. This structure proved to be an ideal mechanical model for reproducing the effect that identifies infrared radiation, and hence an ideal structure for application in detection systems.

The main benefit of this kind of research is the possibility to raise a known material with good characteristics (e.g. silicone) to a higher level. This can be achieved by corrugating the material. In this work, for the first time, examples of different corrugations of the same biological material and the possibilities of their different applications are presented.

3. Conclusions

This work included the examination of different types of butterfly wings and the finding of representatives of certain types of structures. Each representation has a different type of structure and therefore carries different mechanical properties. In this work, for the first time, butterfly wing structure types are classified into separate types of arrangement. These types were recognized as established systems within different structures and their properties served as a parameter to select potential applications. The proposed types of structures are assumed to be biomimetic models for the production of artificial materials that would have applications in the military industry. A material, silicone, has also been proposed as ideal for testing biomimicry and for checking the properties of artificially obtained structures.

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