International Journal of Engineering& Scientific Research
Vol.12 Issue 05, May 2024
ISSN: 2347-6532 Impact Factor: 8.076
Journal Homepage: http://www.ijmra.us, Email: editorijmie@gmail.com
Double-Blind Peer Reviewed Refereed Open Access International Journal - Included in the International Serial Directories Indexed & Listed at: Ulrich's Periodicals Directory ©, U.S.A., Open J-Gage as well as in Cabell's Directories of Publishing Opportunities, U.S.A

Applications of Biomimetics in Textiles - A review

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Abstract

For centuries, artists and designers have drawn inspiration from nature. Every element of nature has been created with a certain role and goal in mind. The natural answers used by nature as a model for problem-solving are used as the basis for biomimicry or biomimetic textiles. The fabrics created with these technologies offer features including thermal insulation, self-healing, structural hues, and functional surfaces. This article explains bioinspired textiles with the aid of a few samples. The area of biomimetic textiles is expanding, and by creating innovative, sustainable textiles, it may realize its full potential.

Keywords:

Biomimetic textile,
Lotus effect,
Nature,
Camouflage,
Functional surfaces

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1. Introduction

Since ancient times, nature has served as an inspiration for designers and artists. Nature was created with certain functioning and a purpose in mind. Nature all around us inspires and generates thoughts that are both existing and executable. Biomimicry is "an approach to innovation that seeks sustainable solutions to human challenges by emulating nature's time-tested patterns and strategies," according to the Biomimicry Institute. The objective is to develop new ways of living that are long-term well-adapted to earthly existence through new goods, processes, and policies [1].

Despite the fact that biomimetics is a relatively new subject, the concept has existed for thousands of years. This word indicates who created all of the substances, tools, mechanisms, and systems ever since the Chinese attempted to produce artificial silk more than three thousand years ago [2].

Otto Schmitt, an American biophysicist, created biomimetic in the 1950s [3,4]. In his 1998 book "Biomimicry," J. Benyus once more put these ideas on the map. He provided knowledge on how to get inspiration from nature and discover these techniques. He has emphasized the necessity for collaboration between many scientific disciplines and recognized biomimicry as a new candidate for science [3]. There are many instances where humans have picked up lessons from nature. Boat hulls that mimic the thick skin of dolphins are an example of bionic engineering. For instance, Leonardo da Vinci used fish and birds to inspire his designs for ships and airplanes, respectively. The development of the radar appears to be connected to the fact that some dolphins and bats have used sound for object identification and communication for millions of years [5]. The natural answers used by nature as a model for problem-solving are used as the basis for biomimicry or biomimetic textiles. The mindset of trying to control or "improve" nature must be replaced with one that mimics its basic principles of operation. By creating a range of new mechanisms and greatly enhancing the functionality of already-existing mechanisms and machines over the course of a few decades of fast development, biomimetics has demonstrated its necessity and viability [6].

1.1 What are Biomimetic Textiles?

The definition of "biomimicry," or mimicking nature, is "copying, adaptation, or derivation from biology" [1]. The words "biomimetics" and "biomimicry" come from the Greek words "bios" for life and "mimesis" for imitation. Throughout history, humans have looked to nature for solutions to issues [7]. Emulating natural systems, patterns, and components is known as biomimetics or biomimicry, and it is used to address difficult human challenges [4]. Natural selection throughout the course of geological time has led to the evolution of structures and materials that are ideally suited to living things. New technologies inspired by biological solutions at the macro- and nanoscales have emerged as a result of biomimetics. Engineering issues including self-healing capacities, environmental exposure tolerance and resistance, hydrophobicity, self-assembly, and solar energy harvesting have been addressed by nature [7]. These methods enable the creation of textiles with features including thermal insulation, self-healing, structural hues, and functional surfaces. The definition of the term, which first appeared in the Merriam-Webster Dictionary in 1974, was "the study of the formation, structure, or functions of biologically produced substances and materials (as enzymes or silk) and biological mechanisms and processes (as protein synthesis or photosynthesis), especially for the purpose of synthesizing similar products by artificial mechanisms that mimic natural ones." [6].

1.2 Biomimetics Inspired by Nature

This section provides information on recent developments in biomimetic textiles and explains how nature serves as inspiration for them.

1.3 Lotus Effect

For various uses, evolution has tailored the wettability of many animal and plant surfaces. Different natural surfaces range in wetting properties from hydrophilic to extremely hydrophobic. The hydrophobic properties of some natural surfaces allow water droplets to roll off of them without soaking them. The lotus leaf surface is a well-known example of this type of surface, and the phenomenon is known as the "lotus leaf effect" [8, 9].

When water is spilled on a lotus leaf, it doesn't soak the surface; instead, the water just beads up and rolls off, clearing the leaf's surface of accumulated dust and grime. Researchers have imitated the "superhydrophobicity" phenomenon to develop water-repellent and self-cleaning materials and textiles. There are two ways to make textiles that can produce the "Lotus effect": the first is to achieve a surface roughness at the nano- or microscale [6,10,11] and the second includes chemical modification to reduce surface energy [6,12]. Lotus leaves have protrusions on their surface, and because of the way they are built, water drops that land on them roll off (Fig. 1). Important technical uses for superhydrophobic surfaces include microfluidics, self-cleaning and antifogging coatings.

In textile applications including outdoor apparel, carpets, architectural materials, etc., superhydrophobicity is crucial. Long before biomimetics gained popularity, it was understood how important water repellency was for textiles [13]. Other uses for textile coverings that resist water include micro fluidics, anti-fogging, and self-cleaning. They are utilized in textiles for buildings, carpets, and outdoor clothes.

Fig. 1 Protrusions present on lotus leaf surface

(Source:https://percenta-nanoproducts.com/lotus-effect/)
(https://futureprospects.wordpress.com/2010/05/17/the-lotus-effect/)

1.4 Structural Colours

Nature has a unique ability to alter light. Most natural surfaces are not only functional; they also create beautiful, vivid, and iridescent colours. Natural colours are frequently formed by a variety of photonic structures that have developed over millions of years to generate effects known as structural colours. Structural colours are caused by interference, diffraction, or selective reflection of incoming light due to the physical properties of a structure [1]. Colour is an important aspect of a textile product, and researching natural structural colours might open up new avenues for developing textile fibres and materials [14].

Despite a lack of colour pigment, the wings of Morpho butterflies seem cobalt blue (Fig. 2). This optical illusion is caused by the multiple layers of protein on the scales of the butterflies' wings, which refract light in different ways. Kuraray Corp., a fibre maker, produced a polyester material with minimal reflectivity but strong colour based on the scale structure of Morpho butterflies. Diphorl was constructed of rectangular cross section fibres [15,1]. Lotus Cars claims to have created a paint that replicates the structural blue colour of the Morpho butterfly [23,7].

Another Japanese company, Teijin Fibres Ltd, has produced a fibre called Morphotex, which is thought to resemble the Morpho butterfly's microstructure as well as its structural colours. This flat-shaped fibre has a thickness of around 15-17 m and is made up of 61 alternate layers of polyester and nylon, each with a thickness of about 70-90 nm. The thickness of the layers, their quantity, and the differing refractive indices (1.6 for nylon and 1.55 for polyester) of the polymers utilized all contribute to structural colours [1,16].

Fig. 2 Morpho Butterfly
(Source: https://blogs.glowscotland.org.uk/sb/aggregate/2016/11/22/the-blue-morpho-butterfly-by-amelia/)

1.5 Spider Silk

Although humans learnt to produce silk from silkworms as early as 3500 BC, spider silk was introduced much later, in the 18th century France. The French colonial authority in Madagascar sponsored spider silk weaving in the late 19th century. Depending on the kind of spider that produces them (there are around 34,000 recognized species [1,17]). The spider (family Theridiidae) makes its web by extruding proteinaceous spider silk from its spinnerets in order to catch insects for eating (Fig. 3). Proteinaceous spider silk is a kind of natural silk that has unrivaled stiffness, strength, extensibility, and hardness [18].

Interestingly, the flabelliform silk utilized in the capturing spiral of the orb spider's web is not adhesive on its own. The spider utilizes other silks and glue to generate stickiness [1,19]. Obviously, replicating spider silk and maybe its production technique appear to be highly appealing. The capacity to generate natural protein fibres with tailorable qualities in a 'green' method to replace energy-intensive, frequently ecologically harmful, and non-recyclable fibres is clearly advantageous [1]. Spider silk is stronger than Kevlar, which is used in bulletproof vests [7,20]. Engineers may employ such a material for parachute lines, suspension bridge cables, artificial ligaments in medicine, and other applications if it could be reengineered to have a long enough life [7].

Fig. 3 The structure of spider silk produced by spider
(Source: https://www.economist.com/science-and-technology/2019/10/10/how-spider-silk-avoids-hungry-bacteria) (https://scitechdaily.com/spider-silk-is-supposed-to-have-healing-properties-scientists-debunk-the-myth/)

1.6 Shark Skin

Humans are not adapted for quick motion in water due to the form of the body, although this may be remedied by a specific swimming technique or by minimizing the friction resistance between water and the skin. To overcome these obstacles, researchers once again resorted to nature [6].

Sharks are among the quickest swimmers in the sea. To swim at high speeds, the frictional drag of the shark's skin on the water must be reduced. Nature has therefore endowed it with such technology, which has evolved over millions of years. The skin of the shark protects it from biofouling and lowers drag as it glides through water. Shark skin is rough and coated with minute placoid scales known as dermal denticles (Fig. 4). The shark's skin is covered with microscopic V-shaped bumps formed of the same substance as its teeth, as seen under a microscope. The scales are oriented along the body's axis on a regular basis [9,20]. The microscale longitudinal ridges impact fluid flow in the transverse direction by restricting the degree of momentum transfer, and the scale height to tip-to-tip spacing ratio plays an important role in minimizing longitudinal and transverse drags [18].

Another notable characteristic of this unique shark scale feature is its microtopography, which works as antibacterial fouling surfaces and makes it difficult for microorganisms to stick to such grooved surface. Scientists are improving swimming suits with antimicrobial textiles that do not require chemical treatments, inspired by natural design. These close-fitting costumes cover a substantial portion of the body and are composed of textiles that are supposed to simulate the qualities of shark skin by superimposing vertical resin stripes. The Riblet effect [18] describes this phenomenon in detail. These riblets form an overall parallel pattern on the shark skin, facing from head to tail in an interlocking pattern. These riblets are found to converge in certain locations of the shark while diverging in others, resulting in variable water flow patterns around the shark in these distinct regions [1,22]. Laboratory experiments have demonstrated that certain configurations of cutaneous denticles reduce friction by 10% [6,21]. Aside from swimwear, materials resembling shark skin have been proposed for uses such as aircraft skin and the interlining of fluid-transport pipes, to mention a few [1].

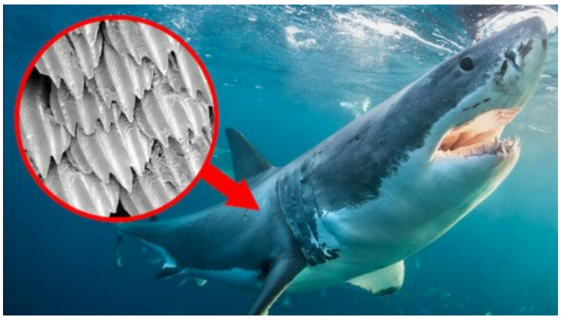

Fig. 4 The structure of scales present on shark skin

(Source: https://www.google.com.hk/amp/s/www.businessinsider.com/shark-scale-design-antibacterial-film-sharklet-stop-bacteria-coronavirus-spread-2020-9%3famp)

1.7 Functional Surfaces

Natural surfaces provide a rich source of inspiration due to the incredible range of their excellent qualities. The dry adhesion of geckos has been extensively investigated, leading to superior biomimetic applications than their natural analog [6]. The gecko has a remarkable gripping ability; it can establish dry adhesion with its wonderful foot (Fig. 5). Geckos, in particular, have evolved the most sophisticated adhesive structures capable of smart adhesion, with the capacity to adhere to diverse smooth and rough surfaces and disengage at whim [9]. Leg attachment pads of various creatures, including many insects (e.g., beetles and flies), spiders, and lizards (e.g., geckos), may adhere to a variety of surfaces and are utilized for movement, even on vertical walls or across ceilings. Attachment systems in such organisms feature comparable structures at their contact points, known as setae [7]. Some amphibians, such as tree and torrent frogs and arboreal salamanders, can cling to and navigate through damp or even flooded surroundings without falling. This type of creature has toe pads that are constantly moistened by mucus released by glands that flow into the channels between epidermal cells. They connect to mating surfaces by moist adhesion and may climb on wet rocks even while water is running over the surface [8].

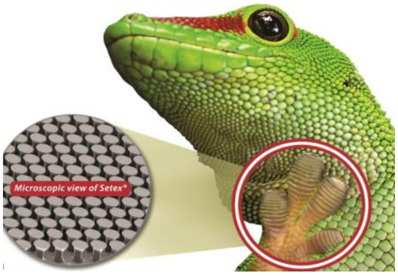

Fig. 5 Setex present on legs of gecko

(Source: https://www.google.com.hk/amp/s/www.dailysabah.com/business/tech/turkish-conglomerate-invests-in-gecko-inspired-adhesive-manufacturer-image-recognition-system-developer/amp)

1.8 Camouflage

Nature is a deadly hide-and-seek game between predator and victim. Both attempt to conceal their identities or visibility from one another in order to live. Some animals have acquired specific abilities to disguise their existence in their surroundings by having distinctive colours, textures, and patterns on their bodies. Camouflage is the phenomena of blending in with one's surroundings. As a result, camouflage is essential in the effort of living organisms to survive. Camouflage may be achieved in a variety of ways. They differ depending on the species. The most prevalent strategies are (i) crypsis, in which the animal merges into the backdrop; (ii) disruptive colouring; (iii) self-decoration using items from their living environment such as twigs, sand, or pieces of shell; (iv) shifting skin pattern and colour; and (v) mimesis. However, altering the skin colour is the most popular concealment technique. Colour, texture, and patterning of the skin are all key factors in concealing. However, most concealment strategies are rendered obsolete by species mobility. As a result, 'active' camouflage works better. Some animals use both colour change and counter illumination to produce active camouflage. The coleoid cephalopods (octopus, squid, and cuttlefish) are examples of this sort of camouflage. They can quickly change their body pattern to camouflage themselves in colourful coral reefs, temperate rock reefs, kelp forests, sand or mud plains, seagrass beds, and other settings [9].

Camouflage occurs in several fishes and amphibians due to outstanding iridescent lateral stripes or spots that change colour from blue-violet in low light to green, orange, and/or red in high light. The reflected indecent colours result from the constructive interference of light from stacks of thin alternating transparent layers with differing refractive indices. The skin of fish and chameleons contains a unique layer of cells underneath their transparent outer skin that is packed with chromatophores or alternating layers of iridophores and guanine crystals. In the Chameleon, a layer of black melanin stored in melanophores is located in deeper skin layers and contains reflecting iridophores, resulting in remarkable concealment [18].

Camouflage tactics have been used by human civilizations for hunting and warfare purposes. However, camouflage has had an impact on other parts of civilization, such as the arts, popular culture, and design. Due to the prominence of inaccurate weaponry on the battlefield in the 18th and 19th centuries, military clothing contained vivid and high-contrast colour combinations to permit differentiation between various troops. However, with the increasing usage of precise weaponry from the 1880s, some type of camouflage for soldiers on the battlefield was created. Beginning with the British Armed Forces, numerous foreign forces adjusted the colours of their clothes to fit in better with the environment, such as khaki or olive drab. That is why olive-green tones became popular in military clothing.

Camouflage textiles, which are used to conceal personnel and military equipment, have become an important component of battle. The key functional requirements for such military materials include not only physical features such as resistance to diverse climatic conditions, water, wind, fire, heat, and specialized combat hazards, but also camouflaging requirements [9,26]. A camouflaged fabric's primary design requirement is to achieve a colorimetric match to its predicted surroundings. This match must span both visible and other colours of the spectrum, as utilized in silicon-based surveillance sensors such as image intensifiers, low-light television, and both near and infrared (IR) devices.

Modern camouflaged garments should give protection not just in the visible spectrum, but also in a wide spectral range, including UV, near infrared, far infrared, radar, and sound ranges. Camouflaging is a method that employs selected forms and colours to create perfect harmony with the surroundings. Combat uniforms (Fig. 6) are used by contemporary armed forces to not only break up the outline of the soldier during the day, but also to offer a distinctive look that makes it difficult to identify them using light amplification devices, such as night-vision systems [9, 27]. Nanotechnology has enabled the development of military clothing that can change design and colour depending on the surroundings. Camouflage that is 'chameleonic' permits the soldier to become a reflection of his environment [9].

Fig. 6 Camouflage army uniform pattern
(Source: https://www.istockphoto.com/vector/camouflage-pattern-background-vector-classic-clothing-style-masking-camo-repeat-gm1222764397-358917532) (https://www.peakpx.com/en/hd-wallpaper-desktop-nezaj)

2. Conclusion

Nature has evolved technologies that can resolve any human problem and persist for a longer amount of time after millions of years of evolution. Fabrics have been used by humans from prehistoric times since they are one of the most fundamental necessities. Nature has provided us with several natural fibres that may be utilized for a variety of reasons. Lotus leaves are very hydrophobic and self-cleaning. One example of structural colours is the Morpho butterfly. Spiders are among the organisms that have the ability to spin continuous threads. The rough surface of shark skin aids in the reduction of drag force. In addition, there are several useful surfaces in nature all around us. These eco-friendly biomimetic or biomimicry fabrics are inspired by nature. Biomimetic textiles is a developing area, and its true potential may be realized through creating and producing sustainable textiles.

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