Butterfly Wings Biomimicked in Textiles

Swapnali R. Vanjiwale
T.Y.Tech.
Dyestuff Technology Department

Reshma Ramakrishnan
T.Y.Tech.
Fibres & Textiles Processing Department

Abstract

Biomimetics refers to the invention and development of materials which are inspired from nature. The morpho butterfly wings are consisting of nanostructured ridges. They exhibit the phenomenon of interference and diffraction. These contribute to the brilliant blue colour of the butterfly. It is indeed an amazing fact that there are no pigments present for colour absorption. Development of Morphotex® by Tejin Limited which is a fabric that is structurally coloured and does not use dye or pigment for coloration. Such fabric eliminates the pollution caused in manufacturing and application of dyes and after treatment of the dyed textile. In today's world when everything is going green and everybody is trying to reduce on pollution it is important to check for pollution caused by dyeing of textiles.

1. Introduction

Nature has always been the first teacher to man. It has taught us to learn and live. Man has, to best of his creativity, aped nature in his life from the start of humanity. The field of mimicking nature to produce technology is known a Biomimetics or Bionics. Structural similarities between nature's gifts and technological innovations are quite popular. Many of the wonderful structures of nature are in the range of nanoscale. With the advent of nanotechnology and the instruments to detect nanostructures in the 21st century, biomimetics is finding new arenas[1].

2. Biomimetics

Biomimcry traces its roots long back ago when the Chinese tried to develop a 'Synthetic silk' 3000 years ago. 'The Eiffel Tower' takes inspiration from the human thigh bone. Artificial surfaces have been created which exhibit self cleaning property of Lotus leaf. George Mestral invented 'Velcro' after observing how the burrs stuck to his dog's coat. The weight distribution observed in ribs and stems of lilypad inspired Joseph Paxton to design the 'Crystal Palace' structure[2].

3. Butterfly Wings

Colour origination from the butterfly wings can be due to the colour pigments present on their wings or by the action of light on the wing scales. The Morpho butterfly species, found in the neotropic ecozones of South America, exhibit brilliant blue and green colours. Study shows that this is due to no pigments but by interference, and diffraction of light by the scales on their wings.

3.1 The morphology of Morpho butterfly

The origination of colours in Morpho menelaus and Morpho rhetenor butterflies has been studied. The fore wings and the hind wings, with a span of 14-18 cm, are brilliant blue. The wings contain large number of scales. The scale surface consists of many ridges. On both sides of each ridge, lamellae are running along the length of the ridge. The lamellae are tilted upwards at an angle to the side of the ridge. They are positioned asymmetrically around the centre of the ridge as shown in Figure 1 and Figure 2. The asymmetric arrangement plays a part in the colour observed. The periodicity of ridges lies between 300 and 200 nm with a total ridge width of between 500 and 700 nm, but despite this, little variation is seen in colour of the butterfly when viewed from different angles. This contradicts the interference phenomena. It is only the intensity of blue colour which varies. The lamellae and the air layers take part in the interference and diffraction of light. The iridescent lamellae are only present on the dorsal side of their wings, leaving the ventral side brown this contributes to the structural colour[3, 5].

Colour without dyes or pigments is the mystery presented by the luminous blue Morpho menelaus butterfly. Its wings are covered with tiny nanostructured scales which diffract the light and which - by interference - eliminate all colours except blue. Unlike chemical pigments, these physical colours never fade. This property also makes them interesting[4].

3.2 Interference and Diffraction

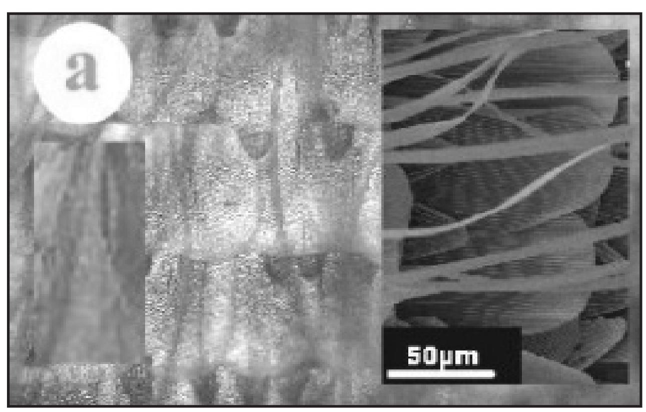

Fig.1 : Wing scales of morpho butterfly[10].

Interference effects are seen in thin films which produce colours of soap bubbles and a slick of oil spreading over small puddles. These

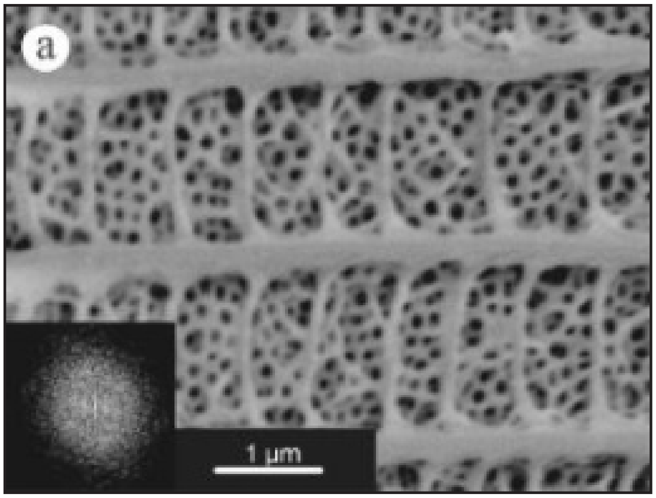

Fig.2 : Ridge structure[10].

films have thickness in the order of 550 nm (same as the wavelength of light). When light is incident on such a film, a small portion gets reflected from the upper surface and majority is transmitted into the film. At the next interface of thin film and air, the transmitted light gets reflected into the thin film and the rest is transmitted into the air. The reflected rays travel along different paths and may be reunited to produce interference. In the butterfly wing case, the lamellae form the thin film and light propagates between the lamellae and air. Depending on the wavelength and the angle of incidence, there can be constructive interference or destructive interference. Constructive interference produces bright regions and destructive interference produces dark regions. The condition for constructive interference is

$$2\mu t \cos r = (2m+1)\,\lambda/2$$

where μ is the refractive index of the cuticle with respect to air, t is the thickness of the lamellae, λ is the wavelength of incident radiation and m is order of interference.

Diffraction is also a form of interference. The bending of light around an obstacle whose dimensions are comparable to the wavelength of light is called Diffraction. Since the ridge gap is between the ranges of 300-2000 nm light bends from the edges of ridge and produces the diffraction pattern. The arrangement of ridges on scales can be compared to the diffraction grating. Hence the positions of principle maxima in the diffraction pattern is explained mathematically by the following equation

$$m\lambda = d \sin \theta$$

where m is an integer, λ is the wavelength of the incident light, d is the gap between the ridges and θ is the angle by which the light wave bends. The thickness and angle of incidence decides the type and intensity of the colour observed[7].

4. Applications

The colour in 'Inverse Opal Films' is due to similar phenomenon as that of butterfly wings. Much research has been done on butterfly wings under the topic of natural photonics. The photonic crystals are those substances which can manipulate the flow of light. The crystal consists of two dielectric materials of different refractive indices, the thickness of which is in order of wavelength of light. The propagation of the light of some specific energy range is prohibited by the crystal. This is created by photonic band gap. The photonic band gap prohibits the flow of light just as the electron band gap does in semiconductors[3].

The Tejin Fibers Limited has reproduced the blue colour of Morpho butterfly by producing fabrics which are structurally coloured, named as Morphotex®. The Morphotex® fabric has 61 alternate layers of nylon and polyester which are having different refractive indices. This corresponds to the ratio of refractive index ratio of butterfly cuticle to that of air which is 1.56. The process of alternate lamination depends upon the type of polymers and their forming temperatures. The forming temperature difference (ΔT) is the difference between a forming temperature T1 of the first polymer and the forming temperature T2 of the second polymer. Generally polymer with a forming temperature of 80°C or less is selected, so that the polymer with lower forming temperature do not degrade at high forming temperature of the other polymer. If the forming temperature difference is more than 80°C, the melt viscosity difference will be large, resulting in nonuniform formation of filament. The second criterion for the two polymers is to meet the refractive index ratio. It is found that the ratio of refractive indices should lie between 1.01 and 1.2. The lower limit for n1 1.3, since most of the polymers have refractive index between 1.3 and 1.7. The lower limit of n1/n2 is taken as 1.01 because if the refractive index is below 1.01, the fiber structure is influenced by fluctuation of refractive index w.r.t. temperature and dispersion, which will cause problems in interference of light and in getting the appropriate colour, even with largely increased number of laminations. The upper limit is kept as 1.2 since composite polymer with forming temperature difference less than 80°C and refractive index less than 1.2 is not found. Hence

$$1.01 \leq (n1/n2) \geq 1.2$$

Morphotex® fiber is spun from a spinneret by composite melt spinning. Composite Melt Spinning carried out at a temperature of 274°C and a take up speed of 1200m/min to obtain a continuous thread with 61 numbers of laminations. Then heat stretching is carried out by a roller stretching machine at a temperature of 90°C and a take up speed of 300m/min to obtain a desired fiber structure.

The reflection spectrum of such a fabric is evaluated by a microspectrophotometer. The results of evaluation are such that the fabric shows a transparent blue and has an anisotropic characteristic i.e. different colour are observed from different viewing points. The reflection peak λ is at 0.47μm or 470nm and the reflectivity is 1.1. Various other synthetic polymers like polymethylmethaacrylate, polyvinylacetate, polystyrene, polyvinylidene fluoride, nylon 66 and polyphenylene sulfide can also be spun to produce alternate layers[8].

6. Advantages

The worldly consumption of dyes is enormous. Dyeing procedures include many chemical substances in addition to these dyes. The dyes mostly are synthetic which possess disposal problems. If left in the open, they are hazardous to environment and life forms. Dyeing without dyes would have seemed impossible 10 years back but now Morphotex®, developed by Teijin Fibers Limited, is a structurally colored textile which uses no dye[9] .It helps in reducing use of chemical substances and energy. This fibre is used for interiors of car and the outer parts of man-made leather shoes. The technological advancement of this unique fabric is highly beneficial for a green environment.

Reference

1. Kapsali V. and Dunamore P., Abbott A., Ellison M., Biologically Inspired Textiles, Woodhead Publishing House, Cambridge, England, 127.
2. Poole, Rebecca, Biomimetics-In Pursuit of Natural Sources of Inspiration, New Cloth Market (2009) Jan 29, 51-54.
3. Vukusic, P. and Sambles, J.R., Photonic structures in biology, Nature, 424, 2003, 852-855.
4. Vukusic, P and Sambles, J.R; Lawrence, C.R; Wootton, R.J; Structural Colour: Now you see it-now you don't; Nature, 410, 2001, 36.
5. Yamada, Jun, Hideshima and Yohsuka, Creation of radiative characteristics by control of surface nanostructure, Thermal Science and Engineering, Vol. 11(4), 2003, 61-62.
6. Vukusic, P and Sambles, J.R., Color mixing in wing scales of a butterfly, Nature, 404, 2000, 457.
7. Avadhanulu and Kshirsagar P. G., Textbook of Engineering Physics, S. Chand and Company Limited, New Delhi, 9th revised edition 2008, 142-177.
8. US PATENT NO. 6326094 B1, "Fibre structure and textile using structural color fibers"
9. http://www.teijin.co.jp/english/ (Accessed in December)
10. http://www.mfa.kfki.hu/int/nano/online/2002_butterfly/index.html (Accessed in December)