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Friction is not a devil

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Tribology in nature: Insects

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ABSTRACT
In this paper, an investigation on the tribological effects in the natural world particularly the insects is explored. This paper aims to i) explain tribology in the natural world, ii) explore effects of tribology in insects, and iii) identify potential use of tribology in insects for human benefits. To achieve these, biological behaviours and characters of potential insects having tribological effects are identified and explained. Extensive literature search on the following keywords (and their combinations) in current online databases (Science Direct, Google and Google Scholar) was conducted: tribology; biotribology; biomimetics; bioinspiration; lubrication; insects; gliding; ecdysis; moulting; burrowing; stridulation. From the literatures, study on the tribological effects in insects have long been done by researchers. Tribological events in some insects have been explained and understood. From these results, it can be concluded that there is numerous tribological events involving the nature. Many insects' behaviour and characters have tribological effects. Some of these have been studied and understood and have the potential to be used for our benefit. Many more to be explored.

1. Introduction

The word Tribology has its roots in the Greek word 'tribo' which means 'rubbing' [1]. Every tribological investigation/study is focussed on friction, wear, lubrication and adhesion aspects [1]. There are various classifications in tribology namely joint, skin, oral, other human bodies or tissues, medical devices and animal tribology [2].

Biotribology (tribology in the biological systems) was first coined by Dawson in 1970, and has been progressing since [2]. Nature also exhibits numerous fascinating tribological events utilizing the four aspects of tribology [3]. It has subconsciously inspired human for many ages in the inventions of many modern technology [1]. The natural systems have played a vital role in the development of science and technology since the evolution of civilizations. Nature exhibits a diverse frictional surfaces from very low friction in case of lubricated systems to very high friction in case of adhesives and in some cases a unique adaptable frictional characteristics. Other terms describing tribology in nature are biomimetics [4,5] and bioinspiration [6].

Amongst tribology in nature that involves animals other than insects have been reported in birds [7-9], bats [9], gecko [4,10], octopus [11] and snake [12]. Numerous tribological events can also be seen in insects. Insects' joints, its integument's contact with its surrounding (through flight or gliding into the air, water or other solid medium), moulting process, stridulation and piercing have tribological effects and are featured in this paper.

This paper aims at i) explaining triboloy in the natural world, ii) exploring effects of tribology in insect, and iii) to identify potential use of tribology in insects for human benefits.

2. Experimental procedure

Literature search was conducted from existing online databases namely Science Direct, Google and Google Scholar. The following keywords (and combinations of the keywords) are used in the search: tribology, biotribology, biomimetics, lubrication, friction,

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moulting, ecdysis, piercing, stridulation, flying, gliding, integument, flight, resistance, insects, friction and adhesion.

3. Results and discussion

The natural world displays so many fascinating tribological events. This can be seen in examples in many animals. Migrating birds such as the albatross that fly extremely long distances have dark wing tops. The temperature difference between bright and dark coloured top wing results into the increase in temperature in dark coloured wing top. This reduces skin drag force over the wing [7]. Muijres et al. [9] compared the efficiency of flying style in bats and birds. They found that morphology, flight style and wake dynamics in the two animals determines the efficiency of their flight mode. One flight mode may be efficient for one type of animal, but not the other. Adhesive force in gecko's foot has also been studied [4,10). The presence of nearly five hundred thousand keratinous hairs or setae on one foot of a gecko [10] is the factor that made them the largest creature capable of producing high force of adhesion with minimum risk [4, 10). The octopus Octopus vulgaris inspires the solution for soft robotics to exert effective forces in unstructured environments [11]. The smart solution of the octopus to crawl, grasp and manipulate with its same limb is suitable to be adopted in the development for a more complex soft robot, which with minimum control, can perform diverse tasks. Specific ventral surface ornamentation of The California King Snake Lampropeltis getula californiae reduces wear by having specific ventral surface ornamentation. Such ornamentation reduces the frictional coefficient and generate anisotropic frictional properties, and reduce stick-slip vibrations during sliding [12].

There are also numerous behaviours and characters in insects that portrays tribological events. This can be seen from the extremely high abundance and diversity of insects in the natural world. We identify four (4) main characters in insects that can be linked to tribology:

3.1 Joint

Joints in some insect species have been found to have friction minimization effects [13,14). The hind legs of orthopteran insects (e.g. grasshoppers, crickets, and katydids) are highly specialized for jumping. Surfaces and textures of the hind femur-tibia joint of katydids (Figure 1) are unique with friction coefficient at its coupling surface of 0.053 + 0.001. Synergistic interaction between the hierarchical surface texture/pattern on the femoral surfaces, nanograded internal nanostructure of the articulating joints, and the presence of lubricating lipids make the joints free from any signs of wear or damage [14].

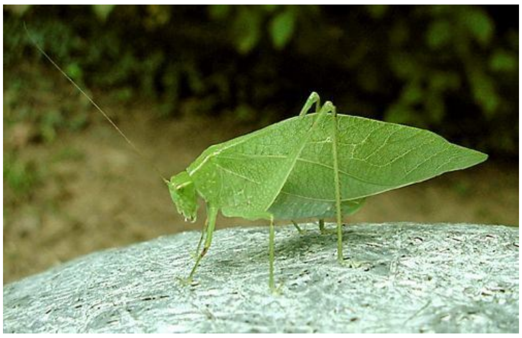

Figure 1: Katydid insect.

In Pachnoda marginata and Geotrupes stercorarius beetles on the other hand, high stiffness of the joint material and hydrophobicity of the joint surface are the two factors that lead to the minimized friction in the joints [13].

3.2 Exoskeleton contact with surrounding

Insect's external skin or its exoskeleton are continuously in contact with its surrounding. This surrounding can be the air [15], water [16] or soil (or wood in the case of wood living insects). Cooper et al. [17] studied the protective layer of the external skin of the American cockroach Periplaneta americana. Wax produced by the roach has lubrication properties that forms thin films and can repel dust (self-cleaning). Superhydrophobic surfaces in insects particularly in ones that live in the water retain air film and ultimately lowers friction [16].

3.3 Integumentary change

Insects undergo several moulting processes in their lives in order to grow. Majority of them also make their way out from their pupae or cocoon into adulthood. Presence of moulting fluid [18-20) has been reported in assisting the process.

3.4 Other body parts with its surrounding

Insects use hairy or smooth adhesive pads to stick to almost all known surfaces [21,22,). Contact between these adhesive pads and the surface substrate is mediated via nanometre-thin films of adhesive fluid [21,22]. Heel pads (euplantulae) in many stick insects and mantophasmids on the other hand functions differently though. Adhesion mechanism does not occur in Euplantulae [23]. Triangular sawtooth microstructures in the mouth fascicle of mosquitoes and cicadas have been manipulated in the invention of bionic drag painless needles [24]. The non-smooth surface structure of the mosquitoes' and cicadas' fascicle with obvious principles of drag reduction effect were adopted in the needles' design. Bionic needle surface's microstructure reduces needles' contact area, form rolling, friction and thus resistance to needle piercing.

In short, there are so many tribological events in nature, particularly in insects that can be manipulated, applied and benefitted for our daily lives. Friction reduction that prevents wear and damage, increase of joint efficiency, enhancement of adhesion mechanism, smart solutions in solving multitasking, self-cleaning, and pain reduction in needle piercing are some tribological events in insects that have revolutionized the well-being of human. They are still many more tribological features in insects that are open for discovery.

4. Conclusion

In conclusion, there are numerous fascinating tribological events that exist in nature. There are many characters and behaviours in insects that involve tribology. All these natural tribological events, particularly in insects can further be studied and adopted in our lives to improve and enhance the quality of our daily lives.

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