Discussion of "Fabrication and Testing of Bioinspired Surface Designs for Friction Reduction at the Piston Ring and Liner Interface" (Maddox, S. R., Gangopadhyay, A., Ghaednia, H., Cai, J., Han, X., Meng, X., Goss, J. A., and Zou, M., 2021, ASME J. Tribol., 143(5), p. 051109)

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The authors introduce an interesting example of practical biomimicry. It is indeed gratifying to see emerging techniques that potentially can bridge the gap in manifesting bioinspired surfaces on an industrial scale (especially in light of the difficulties inherent in abstracting biological analogs to solve engineering problems).

One difficulty often encountered in borrowing from nature is selecting a suitable bio-analogue that potentially can function successfully in an engineering environment. A key condition in this case is to draw compelling parallels between function constraints in the biological realm and those existent within the functional environment of the target engineering domain. In the current work, the authors settled on the hexagonal pattern present in tree frog pads as a bio-analogue for a sliding surface that engages in lubricated friction. By doing so, they elected to work with the hexagonal textural pattern which is complex (albeit seemingly simple).

Hexagonal patterns are frequently encountered in nature and serve various functional purposes. They are present across species from insects to reptiles. They constitute building blocks of a wide spectrum of functional constructs of a domain that varies from complex vision devices in insects to friction controlling structures in reptilia. The differences between individual patterns across species, and functions, are dimension sets and pattern orientation on the surface with respect to the principal motion direction [1]. In species that depend on friction optimization for function, e.g., legless reptiles including snakes, hexagonal patterns differ from those found on species that depend on adhesion control, and regulation of impact or shock absorbance for structural integrity (e.g., frogs and lizards). Hexagonal patterns for frictional optimization, e.g., in snakes, are multi-scale-bi-fractal constructs. On the macroscale, these hexagonal patterns are of anisotropic proportions. They are elongated, with the longest chord of the hexagonal unit cell being perpendicular to the so-called anterior–posterior body axis (which is also the principle axis of motion of heavy snakes that engage in rectilinear propulsion). Such species are relatively heavy and with stocky bodies. During motion, their contact zones experience stresses on a scale analogous to many engineering surfaces. The orientation of the largest chord within the hexagon in this case, i.e., being perpendicular to the major locomotion axis, is advantageous. It reduces friction and thereby optimizes the energy consumed by the reptile. The heaviest the species, the greater the anisotropy in chord lengths [2].

Results of the current work confirm that reduction in friction is a function of the density of the patterns per unit area of the surface as previously observed in snakes. However, the focus on the capacity of the surface to retain a sufficient lubricant volume undermined full exploitation of the benefits of hexagonal patterns in friction as observed in relevant species. Description of the patterns provided in the paper, along with scan electron microscopy (SEM) micrographs, reveal the anisotropic dimensions of the examined unit hexagonal cells. This ratio of anisotropy, given by dividing the longest chord by the shortest chord, varies among the examined surfaces (approximately 1.3 for W10d7t50, 1.5 for W2d2t50, and 1.65 for w10d2t50). The benefit of the elongated hexagon, which as mentioned earlier is a feature of legless reptiles, remained unutilized according to the experimental parameters reported in the paper.

Reciprocating sliding took place parallel to the longest chord, and not perpendicular to it, as observed in nature, for all samples except for two samples (W10d7t50 and W10d2t0). Interestingly, sliding of the two exception samples resulted in a coefficient of friction very close in value to the best performing sample (W10d2t150). This is despite considerable differences in the geometric indices (as reported in Table 2). This suggests that adjusting the orientation of the sliding direction may further reduce friction. Such a result, upon verification, can be useful where local minimum lubrication requirements are not met.

An additional remark concerns the abstraction of tribological surfaces from nature. The results (Fig. 16) imply that the position of the ring from the dimples (lubricant reservoir) is decisive to the friction behavior and integrity of the surface. This suggests that the macro-shape of the pattern, i.e., the hexagon, is less influential than the shape and pattern of the microscale features of the surface. In other words, it is the deterministic micro-features of the biological surfaces that stand to affect both friction and wear of the surface. This confirms earlier studies that compared biological surfaces to honed surfaces based on the analysis of the metrological features of collection of samples from species and actual honed engine cylinder liners [3,4]. The prominence of the micro-features and their deterministic patterns influences the path-forward for futuristic bioinspired tribological surfaces. This is because the size of the features to be implemented and the critical dimensions of the pattern to be implemented. More importantly, in most engines, as well as heavy duty applications, using metals or ceramics is essential.

The pattern replication technique developed by the authors, in essence, belongs to the rapid prototyping family of printing procedures. In this particular case, it was used for pattern replication using polymeric materials. The tribology of polymers, meanwhile, differs from that of metals. To that end, the differences can be substantial in some cases to the extent that they can lower the confidence level in any projected behavior for an off spring metallic surface. As such, this discusser wonders of the developed pattern replication technique which can be applied directly to metallic surfaces? Furthermore, in case of possibility to work with metals directly, what is the anticipated resolution?

References

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