Surface Texturing: Principles and Design

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Surfaces: why live with random surface roughness?

Surface engineering

- Continuous & discrete textures (friction control)
- Thin soft films (lubrication)
- Thin hard films (durability)
- Surface chemistry protecting films (reliability)

Motivation: to reduce friction & increase durability in energy transmission components and engines

Is it possible to achieve 5% reduction in friction and 30% increase in energy transmission efficiency using surface textures, thin films, and surface chemistry?
Surface texturing

• Operating regime classification & mechanisms
  – High speed, low load (15 MPa, 1 m/s)
  – High speed, high load contacts (800 MPa, 1-2 m/s)
  – Low speed, high load contacts (1-3 GPa, <1/m/s)

• The issue of scale
  – mm scale features
  – Microscale features
  – Nanometer scale features
“The white lotus, born in the water and grown in the Water, rises beyond the water and remains unsoiled By the water”  (ancient Indian Buddhist text)
Symbol of Purity
Sharks have used surface texture to lower friction for > 200 M years. Parallel placoid riblets guide fluid flow and prevent sideway turbulence across skin. Riblets do not grow with fish. Sharks typically swim 5-20 km/h, max ~ 40. Riblets may help in glides after spurts.
Scherge & Gorb, Biological Micro-and Nanotribology, Springer 2001, 83

Bechert et al, Naturwissensch. 2000, 87, 157

Fig. 3.2. Shark skin surface. (a) Directionality of the riblet groove pattern in the shark *Isurus oxyrhinchus*. (b) Scale surface of the shark *Sphyra lewini*. (c) Scale surface of the shark *Etmopterus spinax*.

Fig. 3 Above: Longitudinal and cross-flow on a ribbed surface; below: drag reduction performance of various rib geometries.
Golf Balls and Dimples

- Since 1618 “featheries” balls used, goose feathers stuffed inside cowhide pouch, seams inside
- 1848 – smooth gutta percha balls introduced; did not fly as well as “featheries”; after 1880 they were given texture to fly equally as well
- Dimples (in rows) introduced in 1905 (standard 336 in US, 330 in UK); round ones are standard, hexagonal ones may be better

Turbulent flow, less separation, less drag
Laminar flow, larger separation, larger drag
Biomimetics?

• 3M has made ribbed films modeled on the shark skin of fluoropolymers and coated upper fuselage and wings on a Cathay Pacific Airbus A340. Early tests (1999) showed drag reduction of 1% = 1 ton fuel per 7,000 miles or savings of about $100,000/year.

• But biomimetics may not always work. Gray calculated in 1936 that dolphins were not strong enough to swim as fast as they do. That led to the belief that the skin had some unusual properties which facilitated flow and that nature had the optimal solution to all problems (Gray’s Paradox).