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Liquid-Crystal Nanomaterials

Tribology and Applications

Springer

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Preface

The monograph is devoted to a topical issue of the study of lubricity of liquid-crystal (LC) nanomaterials and systems and their application in engineering and medical fields. The theoretical and experimental results of the study of friction, wear, and lubrication of both technical friction units and natural joints containing liquid-crystal cholesterol compounds are adequately presented. Current conceptions of friction and wear of solids, including biopolymers, are given. Moreover, the author's explanation of boundary lubrication in the presence of cholesteric liquid-crystal nanomaterials in a friction area is set out in the monograph. It is noted that liquid-crystal state of synovia is of essence for reduction of intra-articular friction due to the presence of cholesteric liquid-crystal nanomaterials.

A brand-new conception of lubricity of cholesteric liquid-crystal nanomaterials at friction of articular cartilages with friction surfaces anisotropy peculiar to them on submicroscopic layer has come out of the experimental work. An advantage of this conception is that it is based only on physical or rather energetic interpretations not considering the nature of dynamically contacting solids and so can be applied to not only cartilage but any surfaces and friction pairs. Experimental data confirming this concept are also presented.

Many issues on structural organization and biochemical characteristics of synovial mediums taking part in joint moving and friction are discussed. The results of studies on creation of artificial joint fluids containing liquid-crystal nanomaterials inherent to natural synovia and exhibiting its lubricating and biochemical properties are given.

The results of research on change in concentration of mineral and synthetic lubricating mediums containing LC-nanocompounds and taking place in the process of static and dynamic contacting with various materials are well covered in the monographs. It is shown that adsorption of cholesteric liquid-crystal nanomaterials from their oil solutions occurs only at dynamic contact of the friction surfaces, and there is no adsorption at static contact. The direct link is established for pair steel–steel between adsorption of CLCC nanomaterial molecules, inductive when dynamic interaction (triboinduced), and change of friction coefficient.

Authors have paid special attention to description of patent-protected original methods and techniques for tribophysical studies of natural and technical dissipative systems, as well as for control of phase states and phase transmission temperatures of LC-nanomaterials and systems. Precision devices and systems based on the digital circuitry methods are in use. It helps to considerable decrease in measurement errors and gets the high precision of the experiments. With all the above mentioned, we can make a conclusion that the presented experimental material is important for engineering and medicine, which makes the work useful for professionals in friction and wear of solids as well as for medical specialists dealing with problems of prevention and treatment of arthropathy.

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About the Book

The monograph gives the research results of tribological, rheological, and optical properties of liquid-crystal nanomaterials, as well as lubricant media and preparations on their basis. Information of high lubricating and screening action of cholesteric liquid-crystal compounds both in technical friction units and in natural human and animal joints are presented. Some connections between tribological and physical properties of liquid-crystal cholesterol compounds are shown. A conceptual model of lubricity of cholesteric-nematic liquid-crystalline nanostructures is proposed on the basis of physical interpretations. It is noted that this model is general and valid for all surfaces and friction pairs, including biopolymer ones. It also presents applications of cholesteric liquid-crystalline nanomaterials in different friction units and tribosystems, as well as in the medical treatment of joint diseases.

Contents

Acronyms and Nomenclature

AFM	Atomic-force microscope
AM	Arithmetic mean
CE	Cholesterol ester
CLC	Cholesteric liquid crystal
CPG	Cylinder-piston groups
ERF	Electrorheological fluids
FRM	Fuel run-in additive
HUA	Hyaluronic acid
ICE	Internal combustion engines
LC	Liquid crystal
LCCC	Liquid-crystal cholesterol compounds
LM	Lubricating materials
Na-CMC	Sodium carboxymethyl cellulose
OA	Oleic acid
PES-5	Polyethyl siloxane fluid
PG	Plastic greases
PS	Pseudo-synovia
PTFE	Polytetrafluoroethylene
RSR	Relative specific radioactivity
SR	Specific radioactivity
SAA	Surface active agent
SCMC	Sodium carboxymethyl cellulose modulus of tension
SF	Synovial fluid
UDD	Ultradispersed diamonds
UDDG	Ultradispersed diamond–graphite charge
UHMWPE	Ultrahigh molecular weight polyethylene
UPTFE	Ultradispersed polytetrafluoroethylene
VO	Vaseline oil
D	Liquid crystal order parameter
E	Modulus of tension

F_a	Adhesion component of friction
F_c	Cohesion component of friction ия
F_f	Friction force
G	Coefficient of rigidity
I_{fl}	Fluorescence strength
K	Forces of action of body weight part
K_{22}	Elastic constant
M	Forces of action of lateral abductor muscles
R	Resulting compressive forces
S	Lead of the cholesteric spiral
S/2	Minimal thickness of liquid-crystal layer or film
T	Temperature
W	Free energy of liquid crystal
W_s	Surface energy of liquid crystal
W_e	Elastic energy liquid crystal
b	Extrapolative path
d	Thickness of liquid crystal
h	Thickness of lubricant layer
h_i	Range of sinusoidal relief
h_l	Thickness ratio of lubricant layer
Δh	The thickness of the specimen
Δl	Deformation
$\vec{n}$	Unit vector (director)
P	Pressure
$\tilde{p}$	Dimensionless pressure
Δp	Differential pressure
t	Time
v	Speed
Φ	Pressure in the fluid
Θ	Calorific endothermal effect
Ψ	Pressure in the articular cartilage
α	Angle
γ	Angle polarization plane rotation
η	Viscosity
φ	The angle of molecular orientation in cholesteric
λ	Wavelength of sinusoidal relief
θ	The angle of director orientation $\vec{n}$ relatively to the instantaneous direction of the cholesteric major molecule axis
τ	Dimensionless time parameter

Introduction

Analysis of tribology and condensed-matter physics shows that realization of LC-state of boundary layers lattice-ordered on nanolevel in dynamic contact area of bodies of different nature and investigation of their properties are becoming increasingly more important, as the use of rheological and constitutive models developed in liquid crystal physics can be effective for lubricity problem solving and for development of effective methods and means of control of frictional interaction and topography on nanolevel of surfaces of different nature [1–3]. It should be noted that cholesteric liquid-crystal substances occupy a special place and they are considered to be classified as nanomaterials and nanocomponents, as they meet all criteria (molecule size, twisted structure, mesomorphous-ordered state, dependence of spiral lead on definite parameters, etc.). Moreover, they are sometimes quoted as on example of these materials, in which properties are widely used in nature to form unique nanoconstruction, e.g., nucleic acid and the like.

What is more, such liquid-crystal substances are quite often used in nanotechnologies as standard for creation of ordered nanotextures, e.g., mesoporous systems, nanostructured electrodes, and more. Also, introduction of carbon nanotubes into cholesteric LC-basis as advanced sensitizer can contribute to increasing electrical and thermal conductivity and heat resistance, improving mechanical characteristics, changing structure of LC-matrix, and making it with new functional properties [4–6]. Moreover, the molecules' capacity for self-assembly in supramolecular assemblies makes the liquid-crystal compounds the most important material for nanotechnologies [7–9].

At the same time, a great attention to using structured-ordered organic compounds as additive, including biogenic, is representative of present-day tribology. Cholesteric LC-nanomaterials are of the great interest among such materials, in other words the materials which can structure not only at bearing surfaces but at a distance of it under certain thermodynamic conditions due to their chemical structure and also possess properties of liquid.

However, to give a more detailed picture of principles of such liquid-crystal nanomaterials is necessary to examine in more detail what liquid-crystal

compounds represent in general and what is their ranking among well-known solids, liquids, and gases according to their aggregative state, structure, and properties.

The features of the structural behavior, tribology, and lubricity laws of the cholesteric liquid-crystal nanomaterials being developed on the basis of modern concepts of adsorption decreases of solid strength and structural mechanics of boundary layers are presented in the work. A special place is occupied by investigation of friction in biological joints as unique natural rubbing organs. Moreover, the book discusses development of brand-new principles of high-precision tribometry and creation of original devices and hardware for estimation of microstructural properties and phase state of liquid-crystal nanomaterials as well as natural and artificial lubricating media and preparations with them.

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