OGY SERIES, 15

ENCYCLOPEDIA OF TRIBOLOGY

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ELSEVIER
Amsterdam — Oxford — New York — Tokyo 1990

ELSEVIER SCIENCE PUBLISHERS B.V.
Sara Burgerhartstraat 25
P.O. Box 211, 1000 AE Amsterdam, The Netherlands

Distributors for the United States and Canada:

ELSEVIER SCIENCE PUBLISHING COMPANY INC.
655, Avenue of the Americas
New York, NY 10010, U.S.A.

Library of Congress Cataloging-in-Publication Data

Kajdas, Czesław.
Encyclopedia of tribology / C. Kajdas, S.S.K. Harvey, E. Wilusz.
p. cm. -- (Tribology series ; 15)
Includes index.
ISBN 0-444-88401-7
1. Tribology--Encyclopedias. I. Harvey, S. S. K., 1932-
II. Wilusz, E., 1948- . III. Title. IV. Series.
TJ1075.K24 1990
621.8'9'03--dc20 90-44593
CIP

ISBN 0-444-88401-7 (Vol. 15)
ISBN 0-444-41677-3 (Series)

Printed in The Netherlands

PREFACE

The aim of this encyclopedia is to provide information on specific tribological terms. Attempts have been made to keep the information as up-to-date as possible, taking into account both the theoretical and practical aspects of tribology. The reader is referred to relevant publications for most terms.

Numerous journals and books have been consulted in the compilation of this encyclopedia but it is possible that others could have been included. If attention could be drawn to them it may be possible to include them in a subsequent edition.

The multidisciplinary nature of tribology, the conflicting theories and approaches to it found in the literature, plus the fact that definitions of the same phenomenon often differ widely, made our task difficult. A choice had to be made of either the most precise definition or our own interpretation.

Constructive criticism and suggestions for improvement by the reader would be appreciated.

The references for the physical and chemical data have been taken from The Condensed Chemical Dictionary (Ref. 484) and The CRC Handbook of Chemistry and Physics (Ref. 1396).

ACKNOWLEDGEMENTS

The authors wish to record their appreciation to the following:

(1) Radom Technical University;

(2) Paisley College of Technology;

(3) the Secretaries, Anne Murdoch, Gillian Alexander, Lynn Gilmour, Ann Hamilton and Rena Paterson.

ABBREVIATIONS

ASS	atomic absorption spectroscopy
AES	Auger electron spectroscopy
API	American Petroleum Institute
APS	appearance potential spectroscopy
ASLE	American Society of Lubrication Engineers
ASM	American Society for Metals
ASME	American Society for Mechanical Engineers
ASTM	American Society for Testing and Materials
ASU	aryl-substituted ureas
ATF	automatic transmission fluids
AW	antiwear
BS	backscattering
CCS	cold cranking simulator
CLA	centre-line average
CMA	cylindrical mirror analyser
CRT	cathode-ray tube
CRV	cone resistance value
CVD	chemical vapour deposition
DAC	diamidocarbonyl
DBDS	dibenzyl disulphide
DDP	dialkyldithiophosphate
DSC	differential scanning calorimetry
DTGA	differential thermogravimetric analysis
EDAX	energy dispersive X-ray analysis
EDTA	ethylene diamine tetraacetic acid
EDX	energy dispersive X-ray analysis
EHD	elastohydrodynamic
EHL	elastohydrodynamic lubrication
EM	electron microprobe
EP	extreme pressure
ESCA	X-ray photoelectron spectroscopy
FIM	field ion microscopy
ICP	inductively coupled plasma spectrometry
IR	infrared
ISO	International Organization for Standardisation
ISS	ion scattering spectroscopy
LEED	low energy electron diffraction
MDP	metal dithiophosphate
MHD	magneto-hydrodynamic
MOC	mutual overlap coefficient
NLGI	National Lubricating Grease Institute
NMR	nuclear magnetic resonance

PCTFE	polychlorotrifluorethylene
PE	polyethylene
PEEK	polyetheretherketone
PET	polyethylene terephthalate
PETP	polyethylene terephthalate
PFAE	perfluoroalkylpolyethers
PPO	polyphenylene oxide
PTFE	polytetrafluoroethylene
PU	polyurethane
PVA	peak-to-valley average
PVC	polyvinyl chloride
PVD	physical vapour deposition
RF	radio frequency
SAE	Society of Automotive Engineers
SAM	scanning Auger microscopy
SEM	scanning electron microscopy
SIMS	secondary ion mass spectroscopy
TAN	total acid number
TBN	total base number
TCP	tricresyl phosphate
TLC	thin-layer chromatography
VI	viscosity index
XPS	X-ray photoelectron spectroscopy
ZDDP	zinc dialkyldithiophosphate

ABRASION
The wearing away of any part of a material by frictional action of hard particles or hard proturberances [502].
See also: ABRASION RESISTANCE, ABRASIVE WEAR, GOUGING ABRASION, HIGH-STRESS ABRASION, LOW-STRESS ABRASION.

ABRASION RESISTANCE
The ability to withstand scuffing, scratching, rubbing or wind-scouring without the loss of protective properties [502].

ABRASIVE EROSION
Erosive loss of material from a solid surface associated with a displacement of material caused by hard particles moving nearly parallel to the solid surface.
See also: ABRASIVE WEAR, EROSION.
- mechanism of wet abrasive erosion of ferrous metals [568].

ABRASIVE MATERIALS
See: ABRASIVES.

ABRASIVENESS
See: ABRASION.

ABRASIVES
Extremely hard materials used for grinding and polishing metal or other hard surfaces. They may be divided into natural abrasives (e.g. diamond, corundum, emery) and synthetic abrasives (e.g. synthetic diamond, carborundum, boron nitride, alumina). The latter are produced by high temperature reactions. Abrasives are used in the form of powder and the hardest are made of diamond. In polishing, diamond dust is usually embedded in a soft matrix, e.g. in a mixture of stearic acid and a glycol.
- general information on abrasives and selection criteria [482].
- transfer and wear characteristics of aluminium oxide and silicon carbide [676].
- preparation and use of bonded and coated abrasives [832].
- review of ultrahard abrasives [833].
- superhard abrasives: diamond and cubic boron nitride [834].

ABRASIVE WEAR

Removal of any part of material due to friction by hard particles and protuberances. The dominant mechanism of material removal is microcutting. The abrasive wear theory assumes that abrasive particles leave a wear area of the same cross-sectional shape. On the basis of operating stresses, [363] distinguishes three types of abrasive wear: gouging abrasion (impact), high-stress abrasion (crushing), and low-stress abrasion (sliding).

See also: ABRASION, WEAR.

- abrasive wear of aluminium and copper at up to 400°C [383].
- nature and mechanisms of abrasive wear [411].
- abrasive wear under 3-body conditions [506, 512].
- abrasive wear of metals [532, 554].
- abrasive wear in steels [540, 898].
- abrasive-corrosive wear of stainless steels [750].
- abrasive wear in stick-slip motion [819].
- ion implantation improving abrasive wear resistance [826].
- abrasive wear mechanism in hard cobalt-based alloys [835].
- abrasive wear of ceramics [848].
- tests on abrasive wear of some commercial polymers [862].
- wear of reinforced thermoplastics by abrasive papers [863].
- abrasive wear of ultra high strength steel [895].
- synergism between corrosion and abrasive wear [937].
- cutting, ploughing and wedge formation during abrasive wear [1029].
- subsurface deformation in abrasive wear [1105].
- work hardening in designing wear-resistant materials [1106].
- abrasive wear resistance of multiphase solids [1107, 1154].
- abrasive wear of bearing materials [1108].
- field and laboratory wear studies on experimental steels [1109].
- diamond and alumina scratch tests to study abrasive wear mechanisms [1110].
- structure and properties of material related to its abrasive wear resistance [1111].
- abrasive wear in ultrasonic drilling [1112].
- lubricated 3-body abrasive wear [1115].
- abrasive wear on ceramic protected agricultural subsoilers [1117].
- fundamental wear of metals under conditions of controlled humidity [1117].
- factors controlling abrasive wear resistance [1118].
- comparison of 2-body and 3-body abrasive wear resistances of steels [1153].

ABSOLUTE VISCOSITY
See: DYNAMIC VISCOSITY.

ABSORPTION
A process in which one material (the absorbent) takes up and retains another (the absorbate) with the formation of a homogeneous mixture having the attributes of a solution. Chemical reaction may accompany or follow absorption [502].

ACETAL RESINS
Polyformaldehyde crystalline materials having the reactive $(OCH_2)_n$ group. There are homopolymer and copolymer acetal resins. Special types of acetals are glass-filled or polytetrafluoroethylene-filled. The former provide higher strength and stiffness while the latter exhibit very good frictional and wear properties.

ACETIC ACID
CH_3CO_2H
Clear, colourless liquid. Miscible in water, alcohol, glycerine and ether. Bp 118°C; mp 16.63°C; d_4^{20} 1.0492. Highly toxic by ingestion; strong irritant to the tissue. Used in making complex greases.
- effect of acetic acid on calcium-complex greases [297].

N-ACETYLETHANOLAMINE
$CH_3CONHC_2H_4OH$
Brown, viscous liquid. Soluble in alcohol, ether and water. Boiling range 150-152°C (5mm); fp 15.8°C; d_4^{20} 1.122. Slightly toxic.
- tested as a corrosion inhibitor of metalworking fluids [48].

ACIDITY
The number of milligrams of sodium hydroxide consumed by $100cm^3$ of the sample.

ACID NEUTRALIZERS
Additives used in some lubricating oils to neutralise contaminating acids formed by combustion of high sulphur fuel and/or by decomposition of extreme pressure additives.

ACID NUMBER

The quantity of base, expressed in milligrams of potassium hydroxide, that is required to titrate the acidic constituents in 1g of sample.

ACID TREATING

A refining process in which an unfinished petroleum insulating oil is contacted with sulphuric acid to improve its colour, odour, stability and other properties.

ADDITIVE PACKAGE

A specially prepared mixture of several additives to be added to a lubricant.

ADDITIVES

Organic, organometallic and inorganic compounds, or even elements that are added to lubricating oils, metalworking lubricants, metal-cutting fluids, greases, bonded coatings and composites for the purpose of enhancing exisiting properties or imparting new ones. They are added to the primary ingredients of a mixture for a specific functional purpose, usually in concentrations of 0.01 to 5.0%. A class of such compounds produces a physical or chemical effect on the bulk lubricant material or on the surfaces of the friction pair, thus leading to a reduction in friction and wear. The following is a list of the important types of additives: antifoam agents, antioxidants, antiseptics, antiwear agents, corrosion inhibitors, detergents, dispersants, emulsifying agents, extreme pressure additives, friction modifiers, metal deactivators, metal passivators, pour-point depressants, rust inhibitors, thickness agents, viscosity index improvers.

- chemistry and technology of additives [1].
- antiwear and extreme pressure additives [2].
- additives for lubricating mineral oil suspensions and pastes [106].
- effect of different metal oil species in aqueous solution on the surface pressure of monomolecular layers of additives [189].
- types, compositions, functions and mechanisms of action of additives [293].
- application of additives to gear and transmission lubricants [354].
- chemistry of additives; their application to modern automotive and industrial lubricants [355].
- an appraisal of world literature (in the years 1946 to 1966) on selected additives, particularly antiwear and extreme pressure agents [400].
- application, performance and limitations of additives [409].
- evaluation of 29 additives in greases [1591].

ADDITIVES FOR LUBRICATING GREASES

Various kinds of compounds are used in much the same way as in lubricating oils in order to improve their characteristics. Generally, they are oxidation and rust inhibitors, and EP additives. Additives are also incorporated into greases for various other purposes, to improve structural stability, resistacne to bleeding, adhesiveness, stringiness, water resistance, etc.

- chemistry of additives for lubricaing greases and their application [18].

ADHESION

The state in which two surfaces are held together by interfacial forces which may consist of valence forces or interlocking action or both [502].

- mechanical and physico-chemical aspects of adhesion [401].
- general information; broad definition of adhesion [405].
- a literature survey, effect of material properties on adhesion [1592].
- adhesion theory of wear [1593].
- adhesion between denuded metallic surfaces [1594].

ADHESION COEFFICIENT

See: COEFFICIENT OF ADHESION.

ADHESIVE FORCE

In frictional contacts the attractive force between the adjacent surfaces.

ADHESIVE TRANSFER

A phenomenon accompanying adhesive wear and consisting of material transfer from one mating surface to the other.

See also: ADHESIVE WEAR.

ADHESIVE WEAR

Wear by transference of material from one surface to another during relative motion, due to a process of solid-phase welding.

The adhesive theory of wear assumes that the loss of material is caused by the welding of asperity junctions creating wear particles due to fracture of the weaker material near the welded junctions.

Particles which are removed from one surface are either permanently or temporarily attached to the other surface.

- empirical law of adhesive wear [1597].

ADSORBATE
Any substance that is or can be absorbed.

ADSORBENT
Any solid having the ability to concentrate significant quantities of other substances on its surface [502].

ADSORPTION
Atomic or molecular attachment to, usually, a solid surface.
Physical adsorption is attributable to van der Waals' forces and is relatively weak.
Chemisorption involves stronger forces of a chemical nature. A simple distinction is often made in that physical adsoprtion is reversible, the adsorbate being detached on exposure to high vaccum while chemisorbed films can be removed only if energy is supplied, for example, by heating [503].

AEROBIC BACTERIA
Single-celled living organisms that can grow only in the presence of oxygen. Oxygen is the terminal electron acceptor.

AERODYNAMIC LUBRICATION
See: GAS LUBRICATION.

AEROSOL LUBRICATION
A lubrication mode in which a mist of finely divided oil particles is produced.
The aerosol lubrication system normally employs a generator supplied with filtered compressed air which provides the desired oil output of small particles directed to friction surfaces. To control the velocity and amount of the oil applied, a nozzle with a special orifice size is used.
- aerosol lubrication and its application [190].
- experiments with aerosol lubrication of power gearing [198].

AEROSTATIC LUBRICATION
See: PRESSURISED GAS LUBRICATION.

AGEING
The irrerversible change of material properties after exposure to an environment for an interval of time.

AGGLOMERATES

Clusters of particles of compounding materials contained in a continuous rubber phase.

AGGLOMERATION

A process of contact and adhesion whereby the particles of a dispersion combine (coalesce) in clusters of increasing size.

AIR BEARINGS

Bearings using air as a lubricant.

- fundamental information and applications [1120].
- performance characteristics of air thrust bearings [1121].
- air-lubricated foil thrust bearings; advanced development [1122].
- development of two types of air-lubricated foil thrust bearings [1151].

ALIGNING BEARINGS

Bearings with an external spherical seat surface which provides compensation for shaft or housing deflection or misalignment [503].

ALKALIES FOR GREASES

The alkalies most commonly used to saponify fatty materials are calcium, sodium and lithium hydroxides. Calcium hydroxide is used in the form of hydrated lime that should be finely ground and should have a low content of $CaCO_3$ which is an inefficient saponifying base. Usually, limits of max. 3% $CaCO_3$ and min. 92.5% $Ca(OH)_2$ are recommended. Sodium hydroxide, generally in the form of solid caustic soda, should be at least 98% pure. Lithium hydroxide is used as crystalline $LiOH.H_2O$ with LiOH content being min. 54% and carbonate and other alkali metals each less than 1%.

See also: THICKENERS.

ALKALINE EARTH METAL SOAPS

$(RCO_2)_2M$

where M may be Be, Mg, Ca, Sr, Ba, Ra.

Soluble in water. They are derived by heating fatty acids or fats with metal oxides or hydroxides. Calcium soaps are very important for making calcium and calcium complex greases.

ALKALINITY

The alkali concentration or alkaline quality of an alkali-containing substance. It is expressed by the neutralisation number.

- simulation modelling for alkalinity depletion in diesel engines [1123].

ALKYLARYL PHOSPHATES

$(R)_x(Ar)_yPO_4$ where $x + y = 3$

Used as load-carrying additives.

- analysed using spectroscopy and physical methods of separation [240].

See also: PHOSPHATE ESTERS.

ALKYLARYL SULPHONATES

Compounds represented by the general formula R_xArSO_3M, where R_x are long chain paraffin radicals, Ar usually represents the naphthalene or benzene radical, and M represents an alkali or alkaline earth metal. They are petroleum sulphonates, e.g. obtained from mahogany acids, and synthetic products. They are known as effective detergent additives and rust inhibitors for lubricating oils.

ALKYLATED NAPHTHALENE

See: POUR-POINT DEPRESSANTS.

ALKYLATED PHENOL

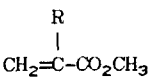
See: POUR-POINT DEPRESSANTS.

ALKYL DIALKYLPHOSPHINATES

Some alkyl dialkylphosphinates have been prepared and tested as extreme pressure additives at equimolecular concentration in mineral oil using the 4-ball machine [41]. Methyl dioctylphosphinate is a slightly more effective extreme pressure additive than isopropyl dioctylphosphinate or n-butyl dioctylphosphinate. A similar situation has been observed with phosphinate esters.

- synthesis, some properties, tribological characteristics and action mechanism of alkyl dialkylphosphinates [41].

ALKYL METHACRYLATES



Monomers derived from methacrylic acid and alcohols, usually C_4 to C_{18} fatty alcohols, used to produce alkyl methacrylate copolymers that have dominated the market as viscosity index improvers until recent years.

See also: VISCOSITY INDEX IMPROVERS.

ALLOYS

An alloy is an intimate mixture of at least two chemical elements, one of which has to be a metal. The properties of alloys often differ greatly from those of their components. They may be divided into ferrous and nonferrous alloys. The former are based on iron, whereas the latter are based on any other metals.

See also: ALLOY STEELS, BEARING ALLOYS, STEELS, SUPERALLOYS.

- basic information on alloys, including refractory alloys and superalloys [482].
- effect of structural changes on improving abrasive resistance of alloys [516].
- new alloys resistant to sliding wear and cavitation erosion [555].
- lubrication requirements in forming and working certain alloys [626].
- scratch tests to study abrasive wear mechanisms in cobalt-based alloys [835].
- sliding behaviour of some copper alloys [836].
- friction and wear of cast Al-Si alloys containing graphite [837].

ALLOY STEELS

Ferrous alloys that, apart from the small amounts of elements present normally in steels, contain controlled amounts (up to 10%) of other metals. The added metals encompassing chromium, manganese, molybdenum, nickel, titanium and vanadium provide improved wear resistance and other properties.

N-ALLYL DI-n-BUTYL PHOSPHOROAMIDATE

See also: DI-n-BUTYL PHOSPHOROAMIDATES.

- tested as an antiwear additive (load-carrying properties)[270].

ALPHA IRON (Fe)

A solid phase of pure iron which is stable at temperatures below 910°C and possesses the body-centred cubic lattice. It is ferro-magnetic below 768°C.

ALUMINA

A naturally occurring mineral essentially composed of aluminum oxide. Electrically fused alumina is used as an important abrasive material; its hardness is close to that of diamond.

See also: ALUMINIUM OXIDE, CORUNDUM, SAPPHIRE.

- friction and wear of alumina against steel [838].
- correlation between mechanical properties and wear resistance of alumina-zirconia composites [1595].

ALUMINIUM (Aℓ)

Silvery-white metal. Density 2.7, mp 660°C. It has good electrical conductivity and high thermal conductivity. Aluminium exhibits high resistance to atmospheric corrosion due to a very tenacious oxide film. It is oxidised by water at 180°C. Its alloys are used for tribological components.

See also: ALUMINIUM ALLOYS, ALUMINIUM BRONZES.

- sliding wear of bearing aluminium lubricated with polyphenyl ethers [130].
- influence of various factors on wear behaviour of aluminium [390, 391].
- abrasive wear tests on aluminium [512].
- aluminium tested in dry and lubricated friction [550].
- pin-on-disc tests with aluminium samples [594].
- wear characteristics [603].
- lubrication requirements in forming and working aluminium [626].
- wear of aluminium rubbing on steel [674].
- effect of water vapour on fretting wear of aluminium [840].
- erosion of aluminium by solid particle impingement [841].
- influence of surface oxide characteristics on friction behaviour of aluminium [842].

ALUMINIUM ALLOYS

A group of alloys containing from 79% Aℓ (high tin aluminium alloy: 20% Sn, 1% Cu) to 95% Al (silicon-cadmium alloy: 4% Si, 1% Cu). Aluminium alloys are light in weight, resist corrosion and accept a wide range of surface finishes. Those of particular importance are high tin aluminium alloy (6% Sn, 1.5% Si) and aluminium-Babbitt (10% Pb, 2% Sn). They are used in many applications, including plain bearings, heavily loaded diesel engine crankshaft bearings, etc.

- oxidative wear of aluminium alloys [694].
- effect of surface oxides on friction behaviour of aluminium alloys [842].
- material removal mechanism in aluminium alloys [946].
- lubricants for metalworking and cutting aluminium alloys [951].
- steel sliding against aluminium alloys: metal transfer [1008].