

Index

Primary emphasis in the index is on the mechanisms and theories of friction and wear. The many interconnecting paths of ideas and terminology expressed by the individual authors are recognized in an abundance of cross-references. Materials used in experiments or identified in accounts of experiences are mentioned when they are given special attention in text or illustrations. The symbol (F) following an entry signifies that information is presented in a figure; the symbol (T), in a table. —M.R.H.

- Abrasion, self (F), 389, 390
- Abrasion mechanism of wear (F,T), 25-29, 75-93, 381-384
 models for (F), 28, 75-77, 85, 87-92, 104-105, 224-226, 227, 351-352
 toughness/strength ratio, 224-225
- Abrasives
 critical attack angles (F,T), 96, 97
 hardness (F), 97-100
 in earth's crust (T), 74, 75
 mechanical properties (F), 97-100, 101
 particle size, shape and orientation effects (F,T), 86, 87, 93-97, 98
- Abrasive wear
 comparison for ceramics, metals and polymers (F), 411-412
 correlation with grooving energy (F), 383, 385, 406-407
 correlation with hardness (F), 88-92, 222, 223, 383, 384
 cost (T), 74, 75
 definition, 73, 188
 effect of material properties (F,T), 100-105, 112
 environmental effects (F,T), 93, 94, 111-114, 302, 306, 311
 examples of steels for (F), 381-384, 385
 indentation fracture mechanism (F), 85-92, 103-105, 439-440, 441-443, 449
 microstructural features (F,T), 105-111, 112, 280-281
 particle generation in (F), 25-29
 plastic deformation mechanism (F,T), 76-84, 88-92, 94, 100-103, 439-440
 relation to adhesive and corrosive wear (F), 188, 189, 389
 relation to fracture toughness (F), 222-226, 227
 relation to impact energy, 222
 terminology, 39, 74
- Acids, effects on abrasive wear (F), 93, 94
- Activated evaporation coating processes, 363
- Activation energy for oxidation in wear (F), 293-294, 295, 325
- Adhesion
 effect of surface films (F), 139, 151-154
 effect of surface roughness, 137-140
 of surface films to substrate (F), 345, 346-347, 348, 350
 Adhesion component of friction coefficient (F), 49, 54-55, 56-57
 Adhesion theory of wear (F,T), 14-15, 29-33, 48-49, 120-124, 133, 189, 217, 274, 326, 351-352, 384-388 (*see also* Asperity-contact model)
 lubricating effect of surface films, 151, 336
 possible support by TEM replica techniques, 270
 standard case of dry sliding, 150
- Adhesive forces
 effect of surface waviness, 138-139
 estimation of, 137-139
 in thermoplastic polymers (F), 410, 411, 416-418
- Adhesive wear
 definition and terminology, 39, 188
 parameters promoting (T), 387, 388
 relation to abrasive and corrosive wear (F), 188, 189, 389
- Air
 dry, wear in (F), 299, 302, 305, 307
 environmental effects on wear (F), 299, 301-302, 305, 307
- Alloying elements for corrosion and wear resistance (T), 332
- Alumina
 coatings of, 359, 367
 correlation of grinding forces with toughness/hardness parameter (F), 446
- Aluminum
 corrosive wear in sodium chloride solutions (F), 318, 322
 effect of water on abrasive wear of (T), 93, 95
 effects of humidity on wear of (F), 301-302, 311
 environmental effects on wear of (F), 93, 95, 299, 301-302, 305, 311
 friction coefficient, 147
 in-SEM wear studies (F), 239-244, 248
 slip systems and Schmid factor, 147, 148
 transmission electron microscopy, 270
- Aluminum alloys, corrosive wear (F,T), 93, 95, 316-323

- Analytical electron microscopes, 273
- Angle of inclination. *See* Surface waviness
- Applications of wear resistant materials
 coatings (F,T), 366-369
 in nuclear reactor service (F), 320-321, 324
 polymers (F), 409-410, 430-435
 shoulder prosthesis (F), 321-322, 324
 special alloys (F), 319-322, 324
 steels (F), 380, 381-384, 385
- Aqueous environment (*see also* Humidity; Water)
 wear behavior in (F), 315-319, 320-323
- Archard's equation, 14, 28, 29, 33, 189, 426
- Argon
 as atmosphere for wear tests (F), 249, 250, 252, 268, 299, 305
 environmental effects on wear (F), 299, 301-302, 305, 307
- Armco iron, friction coefficients (F), 49, 50, 55, 56, 57
- Asperities
 deformation and fracture (F), 17-19, 29-34, 45, 60-61, 190, 191
 forces acting upon (F), 226, 228
 interaction (F), 52-54, 57, 190-193, 384-386
- Asperity-contact model of wear phenomena (F), 14, 28, 29, 52-53, 120-124 (*see also* Adhesion theory of wear)
- Asperity contact spots
 effect of area on friction coefficient, 344-345
 formation (F), 121, 123
 size effects (F), 123-124, 158, 160, 171, 385-386
 surface roughness effects (F), 119, 132-137, 182, 183
 temperature variations (F), 124, 125, 155, 157-161, 323, 325
- Asperity deformation component of friction coefficient (F), 49, 52-54, 56
- Asperity fatigue theory, 191
- ASTM Standard Terminology Relating to Corrosion and Wear, 2
- Atmospheres (*see also* Environment; Humidity; Inert and nonoxidizing atmospheres; Oxidizing atmospheres)
 effect on solid lubricant films (F), 348-350
- Atmospheric pressure, effects on wear and fatigue resistance (F), 214-217
- Attrition (cleavage fracture) (F), 390
- Auger spectroscopy, 237
- Austenite (*see also* Retained austenite)
 abrasive wear resistance (F), 106-108
- Austenitic irons
 relation of abrasive wear to fracture toughness and hardness (F), 223-224, 225, 227
- Austenitic steels
 abrasive wear resistance (F), 106-108
 effect of prehardening on wear (T), 77, 79
 fragmentation during sliding wear (F), 33
 friction layers in (F,T), 399, 400
 strain hardening behavior (F), 81, 82
 wear resistance vs. hardness (F), 88, 89, 90, 92
- Bainite, abrasive wear resistance (F), 106, 107
- Ball and cylinder configuration for wear studies (F), 239-241
- Barrier coatings for chemical vapor deposition, 361
- Basic case of dry sliding, 119, 120, 153-154
 friction coefficients for, 149-150
- Bearings
 ball, 391-393, 403, 405, 406
 coatings for, 366
 foil, 366
 formation and structure of friction layer (F), 403, 405, 406
 high temperature and high vacuum, 366
 rolling, coatings for, 366
 rolling contact fatigue (F), 391-393
 sliding, coatings for, 366
 stresses encountered in coated materials, 357
- Bismuth, friction coefficient vs. sliding speed (F), 163
- Block-on-ring wear test arrangement (F), 6, 7, 249-250, 258
- Body-centered cubic metals
 effect of bulk texture and slip system on friction coefficient, 150
 effect of low temperature and ductility on wear (F), 313, 316
 friction coefficient and Schmid factor, 148, 149
- Bonding, intermolecular, of polymers (F), 413-415, 417-418, 430, 431-432
- Bonding of hard coats, 355 (*see also* Adhesion)
- Bond strength requirements for coatings, 356-357, 358, 365, 369
- Borides for use as hard coatings (T), 353, 354, 367
- Brass
 dependence of wear rate on sliding speed (F), 126, 171
 laminar sheet separation in (F), 20
 structure of wearing surfaces (F), 37-38, 39
- Break-in. *See* Wearing-in
- Brittle fracture in abrasive wear, 85
- Brittle materials
 fracture mechanics analyses of wear, 104, 221, 232
 friction coefficient and Schmid factor, 148
 volume wear and hardness calculations (F), 86-87, 88, 91, 92
 wear mechanisms (F,T), 439-452
- Brittleness, effect on wear resistance of steels (F,T), 378, 386

- Bronze, TEM examination of bearing wear particle (F), 272, 273
- Carbides, hard, for use as coatings (T), 353, 354, 361, 367, 368
- Carbides in alloy structures, effects on wear resistance (F), 108-111, 383-384, 385, 389
- Carbide tools, chemical vapor deposition coating processes, 361
- Carbon dioxide, environmental effect on wear of steel, 298
- Carbon replica techniques for transmission electron microscopy, 271
- Carbon steels
 - dry sliding wear studies (F,T), 250-253, 255-263, 265, 268, 293-294
 - effect of humidity on wear of, 302, 308, 311, 312
 - environmental effects on wear of (F), 299, 302, 305, 308, 311, 312, 314
 - fatigue wear theory (F), 212-214
 - friction coefficient, 50, 53, 55, 56, 57
 - groove formation in cutting (F), 381, 382
 - oxidational wear (F), 293-294
 - plastic deformation in sliding wear (F), 200, 201
 - structure and microhardness profiles of friction layers (F), 399, 401-403
 - wear particle formation in (F), 206, 207
- Cast irons
 - abrasive wear performance data (T), 113
 - effect of carbides on wear resistance (F), 108, 109
 - effect of fracture toughness on wear resistance (F), 221, 222
 - effect of hardness on wear resistance (F), 222, 223-224, 225
 - environmental effects on wear of (F), 93, 94, 309-310, 312
 - Ni-hard, abrasive wear resistance (F), 108
- Ceramics
 - comparison of wear resistance vs. hardness with that of polymers and metals (F), 411-412
 - effect of environment on wear rate, 87
 - lateral fracture model of wear (F), 441-443, 450-451
 - mechanical properties, comparative ranking of (F), 378, 379
 - toughness/hardness relationships (F), 441-442, 446-447, 449-450
 - wear mechanisms (F,T), 439-452
 - wear resistance vs. hardness (F), 88, 89, 90, 92, 411-412
- Chemical vapor deposition coating processes (F,T), 359-362, 366-368, 377
- Chemo-mechanical processes of wear (F), 291-329
- Chlorine, environmental effects on wear (F), 298, 302, 303, 304
- Chromates, frictional behavior (T), 338
- Clays, mechanical properties, comparative ranking of (F), 378, 379
- Cleavage fracture. *See* Attrition
- Coating processes (F,T), 333, 356, 358-365
- Coatings (*see also* Hard coatings)
 - application techniques (T), 332, 333, 358-365
 - classification (T), 332-335
 - compositions (T), 333
 - dependence of wear on, 164, 377
 - functions (T), 333, 334
 - tribological applications (F,T), 366-369
- Cobalt alloys
 - effect of carbides on wear resistance (F), 108-111
 - effect of temperature on wear rate (F), 314, 317
 - use for wear resistant prosthesis (F), 321-322, 324
- Coefficient of friction. *See* Friction coefficient
- Coefficient of wear. *See* Wear coefficient
- Cold work, effect on wear rate and fatigue limit (F), 214, 215
- Compression/shear effects on wear crack propagation (F), 226-231
- Compressive stresses
 - in surface layers, 47, 173
 - on asperities and delamination cracks (F), 64-65, 226-231
- Computers, use for wear test control, 249
- Contact fatigue, cracking and wear processes (F), 390-393 (*see also* Rolling contact fatigue)
- Copper
 - dislocation structures in (F), 180, 181, 204, 205
 - effect of slip systems on friction coefficient, 151
 - effect of surface films on friction coefficient (F), 152, 153
 - electrodeposition onto worn surfaces for transmission electron microscopy, 276, 277
 - energy expended in deformation and wear (F,T), 82, 83, 84
 - environmental effects on wear of (F), 298, 299-300, 302-307, 318, 322
 - fatigue striations on (F), 210, 211
 - formation of microchips in cutting (F), 376
 - friction coefficient vs. sliding speed (F), 163, 347
 - grooving or plowing in (F), 123, 125
 - material displacement in wear scar (F), 2-3
 - micro-roughness in (F), 133, 135, 141
 - recrystallization during sliding wear (F), 180, 282-284, 286, 287

- Copper, *continued*
 shear deformation in sliding (F), 166, 167, 175
 strain distribution and dislocation density (F), 125, 127, 128, 129
 structure of wearing surfaces (F), 2-3, 35-37
 subsurface strain distribution (F), 202, 204
 subsurface wear damage in (F), 277-287
 surface roughness correlation with wear particle size (T), 206-207, 208
 thickness of deformed layer vs. wear volume (F), 207, 208
 transmission electron microscopy (F), 269, 277-287
- Copper-silver solder laminate, strain distribution below surface (F), 78
- Copper-zinc alloy, in-SEM studies (F), 241, 244-245, 246, 247
- Corrosion
 effect on abrasive wear (F,T), 93, 94, 95
 in wear tests using sodium chloride solutions (F), 316-323
 relationship to wear (F,T), 292, 315-319, 320-323, 387-388
- Corrosive wear
 environmental effects (F), 291-329
 in aqueous environments (F), 315-319, 320-323
 relation to abrasive and adhesive wear (F), 188, 189
- Crack length
 calculation for lateral fracture, 441-443, 450-451
 critical, 64, 66
- Crack nucleation and propagation (*see also* Fracture; Lateral fracture)
 direction of crack growth (F), 230-232
 in abrasive wear (F), 85-86
 in contact fatigue (F), 390-393
 in delamination theory of wear (F), 16, 18, 21, 46, 60-67, 164, 209, 391, 392
 in polymers and thermoplastics (F), 67-68, 428, 429, 433
 in sliding wear (F), 206, 209, 226-232, 390-391
 theories of (F), 228-232, 441-443
- Crack propagation rate (F), 66
- Cracks
 delamination (F), 60, 61, 226-231
 similarity of wear crack to fatigue failure, 206
- Critical materials. *See* Materials conservation
- Critical resolved shear stress. *See* Flow stress; Resolved shear stress; Shear deformation; Shear stresses
- Crossed-cylinders wear test arrangement (F), 6, 7
- Cross sections of worn surfaces, definition (F), 8, 9
- Crystal orientation. *See* Slip systems; Textures
- Crystal structure (*see also* Slip systems)
 correlation of friction coefficient with ductility and low temperature (F), 312-316
- Cutting (*see also* Metal cutting; Plastic cutting mechanism)
 vs. flaking mechanisms in abrasive wear (F), 224, 225, 227
 vs. plowing in material removal (F), 26-28, 224
- Damaged surfaces. *See* Deformed layer
- Definitions of wear terms, 1-4, 38-40, 73-74
- Deformed layer (*see also* Friction layers; Surface layers)
 formation in abrasive wear, 77-79, 100-102
 properties and structure as related to bulk material, 375-377
 shear strains in, 165-167, 171-172
 thickness and area in wear determinations (F), 166-167, 171-172, 177-178, 194-198, 200, 202, 203, 204, 205
 thickness vs. wear volume and friction coefficient for steels (F,T), 252-257
 thickness vs. wear volume and particle size (F), 207-208, 209
 zones in, 202, 398, 399
- Delamination theory of wear (F), 16, 18, 20, 21, 43-71, 157
 crack nucleation and propagation (F), 16, 18, 21, 46, 61-67, 164, 209, 391, 392
 elastic-plastic model, 233
 extension to polymers, 67-68, 429, 433
 fracture mechanics calculations in (F), 226-232
 frictional forces in (F), 48-60
 mechanisms and wear rate (F), 60-67, 119, 164, 165, 168, 183
 support by replica methods of transmission electron microscopy, 271
- Dies. *See* Metal working tools
- Dislocation cells
 formation, 144-145, 176-178
 in friction layer of ball bearing steel (cell ferrite) (F), 405, 406
 structure, size and cell walls (F), 120, 144-145, 174, 176-182, 183, 204, 205, 278, 279, 281, 282, 284, 285
- Dislocation concepts
 in delamination theory, 16, 46-48, 183
 in friction and wear (F), 119-186
 in structure of wearing surfaces (F), 35, 38, 39, 120, 176, 183-184
 in wire drawing and rolling (F), 143-144, 174, 176-177
- Dislocation density
 effect of plastic deformation and slip, 144
 effect on flow stress of worn surfaces, 81

- in surface layers, 46-48
 - revealed by electron microscopy (F), 275, 287
- Dislocation glide in slip systems, 142-145, 147
- Dislocations
 - distribution under wear tracks (F), 125-127, 128, 129
- Dispersion hardened materials, strain hardening behavior (F), 81, 82
- Displacement reactions for production of hard coatings (T), 359, 360
- Disproportionation reactions for production of hard coatings (T), 359, 360
- DP steels. *See* High strength low alloy steels
- Dry sliding. *See* Sliding behavior, dry
- Dual-phase steels. *See* High strength low alloy steels
- Ductile materials, volume wear calculations (F), 86-87
- Ductility
 - effect of temperature on ductility and wear, 312-313
 - effect on wear resistance of steels (T), 378, 386
- Earth's crust, abrasives in (T), 74, 75
- Elastic anisotropy, effect on surface roughening (F), 129-131
- Elasticity theory in sliding and delamination wear calculations, 226, 227, 229, 232, 233
- Elastic modulus
 - comparative rankings for various materials (F), 378, 379
 - in lateral fracture model for wear of ceramics, 441
 - in wear rate and wear resistance calculations, 130, 352
- Elastic-plastic deformations
 - asperity interactions (F), 129-131, 191-192
 - in delamination wear models, 233
 - indentations in abrasive wear, 85-86
 - relationships for steels and other materials (F), 378-379
 - shear stresses in deformed layer (F), 130, 200, 202
- Elastohydrodynamic contact in lubrication, 357
- Elastomers, mechanical properties, comparative ranking of (F), 378, 379
- Electrical conductivity, variation with surface films and friction coefficient (F), 152, 153
- Electrodeposition of copper for transmission electron microscopy, 276, 277
- Electron diffraction in study of wear surfaces (F), 274, 280, 281, 284
- Electron emission. *See* Exoelectron emission
- Electron microscopy. *See* Scanning electron microscopy; Transmission electron microscopy
- Electron spectroscopy for chemical analysis (ESCA), 237
- Energy (*see also* Grooving energy; Stacking fault energy; Surface energy)
 - expended in plastic deformation and wear (F,T), 81-83
- Energy criterion for crack nucleation (F), 61, 62, 64, 65
- Energy dispersive X-ray analysis, 236, 238, 284
- Environment
 - aqueous (corrosive) (F), 315-319, 320-323
 - effect of atmospheric pressure on wear and fatigue resistance (F), 214-217
 - effect on abrasive wear (F,T), 93, 111-114, 302, 306, 311
 - effect on wear processes (F), 291-329
 - humidity effects (F), 291, 301-302, 306-310, 311, 312, 420
 - inert and nonoxidizing (F), 291, 297-300
 - oxidizing effects (F), 291, 292-297, 311
 - severe, special alloys for (F), 319-322, 324
 - temperature effects (F), 124, 125, 155, 157-161, 170, 291, 310-315, 316, 317, 323, 325
- Epoxy, void nucleation in (F), 63, 64, 65
- Erosion resistance, coatings for, 366-367
- Evaporation coating processes. *See* Activated evaporation coating processes; Vacuum evaporation coating
- Exoelectron emission, use in wear studies (F), 297, 299, 300, 301
- Face-centered cubic metals
 - effect of bulk texture and slip system on friction coefficient, 150-151
 - effect of low temperature and ductility on wear (F), 312-313, 315
 - friction coefficient and Schmid factor, 147, 149
 - surface texture for sliding wear (F), 148
- Fatigue (*see also* Contact fatigue; Rolling contact fatigue)
 - correlation with wear resistance (F), 212-217, 390, 391
 - effect of atmospheric pressure (F), 214-217
 - effect of cold work (F), 214, 215
 - effect of humidity, 301, 302
 - in oxidative wear mechanisms (F), 292, 294, 296
 - low-cycle, as wear mechanism, 22, 189
 - role in sliding wear (F,T), 187-219, 228, 232
- Fatigue fracture
 - correlation with sliding distance (F), 212
 - in surface of punching tool (F), 376
 - probability factor, 190-191
 - similarity to wear cracks, 206
- Fatigue striations (F), 210, 211

- Fatigue theories of wear (F), 189-205, 217
 substrate theory (F), 193-198, 212
 subsurface effects (F), 199-205
- Ferrography, 188, 190, 238, 272
- Films. *See* Low shear strength films; Oxide films; Surface films
- Flaking (*see also* Delamination theory of wear)
 in abrasive wear mechanisms (F), 19, 188, 221, 224, 225, 227
- Flint abrasives (F), 90, 92, 98
- Flow characteristics of worn surfaces (F), 100-103
- Flow stress. (*see also* Resolved shear stress)
 effect of slip systems, 140-142
 effects on shear deformation, 142, 156, 170-175, 183-184
 in surface layers (F), 46-48, 81, 82
 of strained vs. unstrained materials (F), 81, 82
- Foils. *See* Thin foil methods of transmission electron microscopy
- Formvar replica method for transmission electron microscopy, 270
- Fracture (*see also* Fatigue fracture; Lateral fracture; Tribo-fracture)
 effect of stress/strain distribution, 157
 in abrasive wear mechanisms (F), 85-92, 103-105
 location in sliding wear, 162-164
 of interacting asperities (F), 29-33, 190-191
 of work-hardened surfaces (F), 33-34
 relationship of mechanical properties to (T), 378-379
 surface studies by transmission electron microscopy, 271
- Fracture mechanics
 in abrasive wear mechanisms (F), 104-105, 222-226, 227
 in sliding wear mechanisms (F), 226-232
 models for brittle materials, 104-105, 221, 232
 surface and subsurface effects, 232
- Fracture stress, comparative ranking for various materials (F), 378, 379
- Fracture threshold for lateral cracking (T), 439-440, 441, 442, 449
 wear rates below threshold, 449
- Fracture toughness (*see also* Toughness; Toughness/hardness relationships)
 dependence of wear resistance on (F,T), 221-222, 224-226, 378-379, 428-429, 432
 effect on wear resistance of ceramics (F), 449-450
 relation to abrasive wear resistance (F), 222-226, 227
 relation to indentation size and hardness (F), 85, 88-93, 103-105
- Fragmented surfaces. *See* Surface layers
- Fretting wear
 environmental effects on, 296, 298, 301-302, 306, 308-310
 humidity effects, 318, 319, 323
 mechanism of, 40
- Friction
 correlation with wear data, 7
 dislocation concepts in (F), 119-186
 genesis of (F), 48-60
 in asperity contact (adhesion) theory, 52-53, 121, 122, 336-339
 static vs. dynamic, 49-51, 52, 53, 56, 58
 time-dependent stages (F), 49-51
- Friction coefficient
 adhesion component (F), 49, 54-55, 56-57
 as an indicator of wear, 325-326
 as factor in coating material selection, 353
 asperity deformation component (F), 49, 52-54, 56
 as related to wear resistance of polymers (F), 409-411, 426-427, 431-435
 calculation involving critical resolved shear stress and Schmid factor, 145-150
 correlation with shear strength as function of temperature (F), 341-342, 343, 344
 correlation with wear coefficient (F), 168-169
 correlation with wear depth (F,T), 252-257
 correlation with wear rate (F,T), 161-162, 252-257, 268, 326
 effect of abrasive penetration depth (T), 82
 effect of asperity contacts using solid lubricants (F), 340
 effect of film thickness (F), 345-346, 347
 effect of flow stress and slip system, 119, 140-150
 effect of hardness variations on, 88, 92, 155, 157-164, 165, 222, 223, 256, 312
 effect of load for lubricating films (F), 343, 345
 effect of oxygen partial pressure (F), 296, 297, 298, 326
 effect of pH and ion concentration in aqueous solutions (F), 317-321
 effect of polymer molecular structure and morphology on (F), 423-426, 431
 effect of sliding distance and direction (F,T), 49, 50, 150-151, 252-257, 324, 423, 424
 effect of sliding speed (F), 160-161, 162, 163, 346, 347, 422
 effect of sliding time on lubricant film formation and wear (F), 340
 effect of surface films (solid lubricants) (F,T), 151-155, 336-349
 effect of surface melting (F), 161, 163
 effect of surface roughness (F), 57-58, 59, 131, 349, 425
 effect of temperature (F), 157, 158, 311-315, 316, 420-422, 434

- effect of temperature using solid lubricants (F), 341-342
- effect of wear particle removal (F), 48-49
- environmental effects (F), 48, 296, 297, 298-300, 302-304, 306, 307, 311-315, 316, 318-321, 324, 348
- equations for, 52, 54, 55, 140, 142, 146, 148, 154, 160, 336-339, 342-344, 419
- for polymers (F,T), 409, 411, 419-425
- for standard case of dry sliding, 149-150
- in adhesion theory (F), 48-49, 151-155, 326
- plowing component (F), 49, 55-57, 58
- stress effects on (F), 62, 140-141, 156, 159-160
- surface energy effect in polymers (T), 419-423
- temperature effect in polymers (F), 420-422, 434
- vs. wear depth and wear volume for steels (F,T), 252-257
- Friction forces (*see also* Tangential force)
 - in polymers (T), 419-426, 430-431
 - in wear theory (F), 48-60
- Friction layers (F,T), 393-408 (*see also* Deformed layer; Surface layers)
 - examples of structures and microhardness profiles for steels (F), 399-407
 - hardness profiles (F,T), 393-398, 399-404, 406
 - internal structures (F), 395, 398-399
 - phase transformations in (T), 395-396
 - wear properties (F), 405-407
 - zones (F), 398, 399
- Friction martensite in steels (F), 398, 399, 401, 402, 403, 405
- Friction space diagram (F), 57-58, 59
- Geometrical effects on friction and wear (F), 93-97, 148, 155, 183
- Glass-bead-filled epoxy. *See* Epoxy
- Glasses
 - crack nucleation and propagation in (F), 86
 - effect of water on abrasive wear of (T), 93, 95
 - impact cracking in (F), 376
 - lubricating effect on friction coefficient (T), 336, 338
 - morphology of polymers, 414
- Glassy thermoplastics. *See* Polymers, crystalline vs. amorphous
- Gold
 - effect of atmospheric pressure on wear and fatigue resistance (F), 214-216
 - production of coatings by pyrolytic decomposition, 359
 - shear deformation in sliding (F), 141
- Grain boundaries, similarity to dislocation cell walls, 179
- Grain size
 - effect on dry sliding wear of three steels (T), 252, 263
 - effect on material removal in machining of ceramics, 446-447, 450
- Grain structure of deformed wearing surfaces (F), 36-38, 39, 47, 84, 279, 281-287
- Graphite
 - as solid lubricant (F), 170, 335, 341, 347, 348, 350
 - friction and wear coefficients (F), 169
- Grinding (*see also* Machining; Metal cutting)
 - abrasive action of (F), 383
 - energy expended in deformation and wear (F,T), 83
 - material removal data for ceramics (F), 445-447
 - thermal effects on wear of ceramics, 448-449
- Grinding forces, correlation with toughness/hardness parameter (F), 445-447
- Groove formation (*see also* Asperity contact spots, formation; Plowing)
 - in abrasive wear of steels (F), 381, 382, 406-407
 - mechanism and calculation of, 76, 77, 81, 95, 97, 100-102, 103
- Grooving energy
 - correlation with abrasive wear resistance (F), 383, 385, 406-407
 - effect of repetitive grooving (F), 406-407
- Gun tubes, coatings for, 366
- Hadfield steel
 - formation of friction layer (F), 407
 - hardness profiles of friction layers (F), 396, 399, 400
- Halide reduction coating processes (F,T), 359-361
- Halides, lubricating effect on frictional behavior (T), 336, 337
- Hard coatings
 - abrasive wear performance data (T), 113
 - bond strength requirements, 356-357, 358, 365, 369
 - coating processes (F,T), 333, 356, 358-365
 - contacts with lubrication (contact stress and conditions), 357
 - high-temperature vs. room temperature coating processes, 356
 - material selection (T), 333, 334, 352-354, 357-358
 - thickness requirements, 355-356, 358
 - wear mechanisms for, 351-352
- Hardening, linear. *See* Work hardening
- Hard facings. *See* Hard coatings
- Hardness
 - as factor in material removal (F), 25-26, 87-92

Hardness, *continued*

- associated with slip lines and roughening (F), 128, 131
- correlation with abrasion resistance of steels (F), 383, 384
- correlation with grinding and machining forces for ceramics (F), 445-447
- depth profiles for friction layers (F,T), 79-81, 393-398, 399-406
- effect of temperature (F), 155, 157-161, 312
- effect of variations on wear resistance, 88-92, 164, 222, 223
- effect on dry sliding wear of three steels (F,T), 252, 256, 263, 268-269
- effect on friction coefficient of polymers (F,T), 423, 424
- effect on wear rate of ceramics (F), 449-450
- effect on wear resistance of polymers (F), 427, 430, 431, 432
- in lateral fracture model for wear of ceramics (T), 441, 442
- of abrasives vs. worn surfaces (F), 97-100
- of variously strained surfaces (F,T), 77, 79-81
- microscopic measurements, 236
- relationship to wear resistance and fracture toughness (F), 101-105, 222, 223, 226, 441-442, 446-447, 449-450
- relationship to Young's modulus and hardness of abrading material, 352
- relation to depth and area of indentation, 136-137
- vs. volume wear (wear resistance) (F), 88-92, 165
- vs. wear depth distribution (F), 79-81, 100-102, 103, 200, 203
- vs. wear resistance for different abrasives (F), 88-92
- vs. wear resistance for metals, ceramics and polymers (F), 411-412

Hardness (coatings)

- estimation for wear resistance, 352, 355
- of typical materials for wear resistance (T), 353, 354
- relation to surface energy, 355

Hardness depth profiles of friction (deformed) layers (F,T), 79-81, 393-398, 399-404, 406**Hardness/toughness relationships. *See* Toughness/hardness relationships****Hard surfacing. *See* Hard coatings****Heat (*see also* Temperature)**

- effect on asperity contact spot, 124, 125, 155, 159, 161
- effect on wear mechanisms of ceramics, 440, 448-449
- generation and dissipation during wear, 84, 155

Heat conductivity. *See* Thermal conductivity**Heavy ion bombardment. *See* Sputtering processes****Helium, environmental effect on wear of steel, 298****Hexagonal close-packed metals**

- effect of bulk texture and slip system on friction coefficient, 150
- effect of low temperature and ductility on wear (F), 313, 316
- friction coefficient and Schmid factor, 147, 149

High speed steel. *See* Tool steels**High strength low alloy steels**

- delamination wear (F), 392
- dry sliding wear studies (F,T), 250-254, 256, 257, 259, 263-268

grooving energy (F), 406-407**Hoop-stress theory of crack growth. *See* Maximum hoop-stress theory****Hot spot temperature. *See* Asperity contact spots, temperature variations; Temperature, variations at contact spot****Humidity (*see also* Aqueous environment; Water; Water vapor)**

- effect on low shear strength films (F), 348
- environmental effects on wear (F), 291, 301-302, 306-310, 311, 312, 420

Hydrodynamic contact in lubrication, 357**Hydrogen, environmental effects on wear (F), 299-300, 306, 307****Hydrogen reduction of halides. *See* Halide reduction coating processes****Hydroxides, lubricating effect on frictional behavior (T), 337****Inclusions, effect on crack nucleation (F), 61-63, 164****Indentations in abrasive wear**

- as source of lateral cracks in ceramics, 441-442

behavior of hills in (F), 134-136

- critical size, 85, 104-105
- size, shape and depth effects (F), 76, 83, 85-86, 90-92, 100-102, 136-137

Indium, as solid lubricant (F), 343, 345**Inert and nonoxidizing atmospheres, effects on wear (F), 291, 297-300****In-SEM wear studies. *See* Scanning electron microscopy****Internal stress, effect on wear (F), 213-214****Ion bombardment. *See* Ion plating; Sputtering processes****Ion plating (F), 362-363**

- applications, 367, 368

Ion scanning spectroscopy, 237**Iron**

- dislocation structure and shear strains in drawn wire (F), 173, 174, 178

- effect of temperature on wear of, 311-312
 environmental effects on wear of (F), 297-304, 309
 oxidational wear studies by exoelectron emission (F), 297, 299, 300, 301
- Iron-chromium alloy, oxidational effects on friction and wear (F), 296, 297, 298
- Lateral fracture**
 crack extension, 440, 441-443, 450-451
 crack length, width and depth determinations (F), 442-443, 444-445, 450-451
 effect of normal, applied and grinding forces on (F), 444-447
 mechanism of (F), 439-444
 model for ceramics wear mechanism (T), 441-444, 450-451
 thermal effects on, 440, 448-449
 velocity of, 443-444
 volume of (F), 443, 444-445, 449
- Layers.** *See* Deformed layer; Friction layers; Surface layers
- Layer-type materials**
 effect of bulk texture and slip system on friction coefficient, 150
 friction coefficient and Schmid factor, 147, 149
 wear coefficients (F), 169-170
- Lead**, use as solid lubricant compound (F), 341, 342, 346
- Light microscopy**, use in conjunction with SEM or TEM, 236
- Linear elastic fracture mechanics.** *See* Elasticity theory; Fracture mechanics
- Linear variable differential transformer (LVDT)**
 for measurement of contact displacement, 249, 253
- Linear work hardening.** *See* Work hardening
- Low alloy high strength steels.** *See* High strength low alloy steels
- Low shear strength films (F,T)**, 335-350
 continuous vs. asperity films (F), 340
 effect of atmospheres on friction coefficient (F), 348-350
 effect of contact area on friction coefficient, 344-345
 effect of film thickness (F), 345-346, 347
 effect of load on friction coefficient (F), 343, 345
 effect of sliding time on film formation and film wear (F), 340
 effect of velocity on friction coefficient (F), 343, 346, 347
 endurance life, 368
 models of frictional behavior, 336-346
 sliding wear mechanisms, 331, 336-339, 350
 substrate effects (T), 346-348, 349
 temperature effects (F), 341-342, 344, 345
 types (T), 335-336
- Lubricants**
 additives, 334, 335
 corrosion products as (F), 317
 for non-ferrous materials, 368
 oxide films as, 295-296, 300, 319, 336, 338
 study by replica technique of transmission electron microscopy, 270-271
 water as (F), 306, 317, 420
- Lubricants, solid (T)**, 335-350 (*see also* Low shear strength films)
- Lubricated vs. unlubricated wear**, 217-218
 transmission electron microscopy for debris studies, 272
- Lubrication**
 by surface films (F), 151-152, 300
 hydrodynamic and elastohydrodynamic contact stresses and conditions, 357
 mechanism of, 335
- LVDT system.** *See* Linear variable differential transformer
- Machining**
 chip formation as a wear mechanism (F), 25-29
 coated cutting tools for, 367
 material removal data for ceramics (F), 446-447
 stresses encountered in coated materials, 357
- Magnetron sputtering**, 365, 366
- Manganese steels.** *See* Hadfield steel
- Martensite** (*see also* Friction martensite)
 abrasive wear resistance (F), 106, 107
 in friction layers in steels, 398, 399, 401, 402, 403, 405
- Martensitic irons**, relation of abrasive wear to fracture toughness and hardness (F), 223, 224, 225, 227
- Martensitic steels**, strain hardening behavior (F), 81, 82
- Martensitic transformation**, effect on hardness depth profiles of steels (F,T), 395, 396, 399
- Material removal**
 mechanisms (F), 25-29, 75-93, 439-441, 449
 rate calculations and measurements (F), 439-440, 443-447, 449-450
 volume calculation for ceramics (F), 443, 444-445, 449
- Materials conservation (T)**, 332
- Materials handling equipment**, wear performance data (T), 113
- Materials selection for abrasive wear resistance (T)**, 111-114
- Maximum hoop-stress theory of crack growth (F)**, 229, 230
- Mechanical properties**
 effect on abrasive wear (F,T), 100-105, 112

- Mechanical properties, *continued*
 effect on dry sliding wear of steels, 263, 265, 268-269
 ranking for various materials (F), 378-379
 relationship to deformation or fracture (T), 378-379
- Melting at surface, effect on friction coefficient and wear rate (F), 161, 163, 170
- Melting points of polymers vs. metals (T), 416, 418
- Metal cutting (*see also* Cutting; Machining)
 abrasive mechanism of (F), 381-384, 385
 built-up edge compared to prow formation (F), 387, 388
- Metal cutting tools
 abrasive wear mechanism (F), 381-384, 385
 coatings for, 367
- Metal films, lubricating effect on friction coefficient (T), 336, 337
- Metals
 mechanical properties, comparative ranking of (F), 378, 379
 thermal conductivity, melting points and surface energy compared to those of polymers (T), 416, 418
 wear resistance compared to that of polymers and ceramics (F), 411-412, 435
- Metal working tools, coatings for, 367-368
- Microalloyed steels. *See* High strength low alloy steels
- Microbands, in deformation of wearing surfaces (F), 36-38
- Microchips (*see also* Wear particles, chip-like)
 formation by plastic deformation, 76, 84, 96
 formation in copper by hard-particle cutting (F), 376
- Microhardness. *See* Hardness
- Micronized surfaces. *See* Deformed layer; Surface layers
- Micro-roughness (*see also* Surface roughness)
 at asperity contact spots (F), 132-137, 182, 183
 at locations of hills in grooves (F), 134-136
 effect of slip and elastic anisotropy (F), 128-132, 133
 effect on friction coefficient, 149
 effects of surface films, 152
 in models for friction and wear (F), 119, 121, 132
 in relation to wear particles, 162-164
- Microscopy. *See* Light microscopy; Scanning electron microscopy; Transmission electron microscopy
- Microstructure, relation to abrasive wear (F, T), 105-111, 112, 280-281
- Microtopography. *See* Topography
- Minerals, wear resistance vs. hardness (F), 88, 89, 90, 92
- Minicomputers. *See* Computers
- Minimum strain-energy-density theory of crack growth (F), 230, 231
- Mining equipment, materials performance (T), 113, 383
- Models of wear phenomena
 abrasive wear (F), 28, 75-77, 85, 87-92, 104-105, 224-226, 227, 351-352
 adhesion theory (F), 14-15, 120-124, 133, 189, 274, 326, 351-352
 asperity-contact (F), 14, 28, 29, 52-53, 120-122
 delamination theory, 52-58
 engineering model, 192
 fatigue theory (F), 189-193, 217
 for hard coatings, 351-352
 fracture mechanics in, 224-226, 233
 frictional behavior of soft films, 336-346
 lateral fracture model for ceramics (T), 441-444, 450-451
 modification by inclusion of micro-roughness (F), 121, 132, 133, 134
 oxidational, 293-295
 plowing or grooving (F), 122-124
- Moisture. *See* Aqueous environment; Humidity; Water; Water vapor
- Molecular structure of polymers (F), 412-414, 415, 427-431, 432-434
 effect on frictional forces (F), 423-425, 431
- Molybdates, frictional behavior (T), 170, 338
- Molybdenum disulfide as solid lubricant (F, T), 335, 341, 343, 345, 346-349, 350
- Morphology of polymers (F), 414-416, 423-426, 427-430, 433, 434
- Neutron irradiation, wear resistant materials for (F), 320
- Nickel
 effect of atmospheric pressure on wear and fatigue resistance (F), 214-216
 environmental effects on wear of (F), 298, 304
 plastic deformation in sliding wear (F), 200, 201
 thickness of deformed layer vs. wear particle size (F), 207, 209
- Nickel-chromium alloys
 effect of temperature on wear rate (F), 310-311, 313-314
 oxide film formation on, 296
- Nickel-copper alloy, fatigue striations on (F), 210, 211
- Nitrides for use as hard coatings (T), 353, 354, 365, 367, 368
- Non-ferrous materials, lubricants and coatings for, 368
- Nuclear reactors, wear resistant alloys for (F), 320-321

- Oil-lubricated systems
 study by transmission electron microscopy, 270-271
 wear particles in (F), 15, 16, 17, 21, 23, 34
- Optically stimulated exoelectron emission. *See* Exoelectron emission
- Orientation textures. *See* Textures, surface
- Oxidation
 activation energy for wear (F), 293-294, 295, 325
 parabolic rate law (F), 292-294, 296
 relationships to temperature and wear, 325
- Oxidational theory of wear, 34, 294-295, 325
 study by exoelectron emission (F), 297, 299, 300, 301
- Oxide attrition in oxidational wear (F), 293, 294
- Oxide films
 effect on friction coefficient and sliding behavior (F,T), 152, 292, 336, 338
 in mild wear mechanism (F), 34-35
 lubricating action (T), 295-296, 300, 319, 336, 338
 thickness effects, 295-296
- Oxide glaze. *See* Oxide films
- Oxide replica method for transmission electron microscopy, 270
- Oxides (*see also* Oxide films)
 distribution in friction layer of tool steel (F), 403, 405
 formation of wear particles (F), 34-35
 for use as hard coatings (T), 353, 367
- Oxidizing atmospheres
 effect on wear processes (F), 291, 292-297, 311
- Oxygen
 environmental effects on wear (F), 295-296, 298-299, 302-305, 325
 partial pressure effect on friction coefficient and wear rate (F), 296, 297, 298, 326, 388
- Particles. *See* Wear particles
- Pearlitic steels
 abrasive wear resistance (F), 106, 107
 structure and microhardness profiles of friction layers (F), 399, 401
 wear resistance vs. hardness (F), 88, 89, 90, 92
- Performance data, use in materials selection for wear resistance (T), 111, 113
- pH (*see also* Acids)
 effect on wear in aqueous solutions (F), 93, 94, 316-321, 323
- Phase transformations, effect on friction layers in steels (T), 395-396
- Physical vapor deposition processes, 363, 365, 377
- Pin and ring combination, effect of heat and hardness on friction, 155
- Pin-on-disk wear test arrangement (F), 5, 7
- Pitting wear, mechanism of, 40
- Plastic cutting mechanism of material removal (F), 440, 449, 450
- Plastic deformation
 as abrasive wear mechanism (F,T), 76-84, 88-92, 94, 100-103
 effect on friction force in polymers, 419-422, 426
 in sliding wear studies (F), 240, 245, 248, 258, 259, 265
 relationship to fracture and wear, 378-379
 subsurface effects in fatigue theory (F), 199-201, 202
- Plastics. *See* Polymers; Thermoplastics
- Plastic zone
 development between sliding asperities (F), 17, 19, 30
 in abrasive wear, 98, 100, 448
 in ceramics, effect on lateral fracture, 441-442, 448-449, 450-451
- Plowing (*see also* Groove formation)
 in abrasive material removal (F), 27, 95, 96, 224, 227, 381
 in frictional behavior of soft films, 336-337
 model for (F), 122-124
 nature of, 27, 45, 59
- Plowing component of friction coefficient (F), 49, 55-57, 58
- Polyamide (PA)
 molecular structure and morphology (F), 413, 425, 427
 relation between friction and wear, 410, 426
 wear comparison to other polymers (F), 426, 429-430, 431, 434
 wear mechanisms (F), 433
- Polycrystalline structures in surface layers (F), 274, 277, 279-285
- Polyethylene (PE)
 molecular structure and morphology (F), 413, 427
 wear vs. that of other polymers, 430, 432
 wear mechanisms (F), 433
- Polyethylene, high density (HDPE), wear comparison to other polymers (F), 429, 431, 434
- Polyimide (PI), wear comparison to other polymers (F), 429, 430, 434
- Polymers
 adhesive forces, 410, 411, 416-418
 as solid lubricants (T), 336, 341
 crystalline vs. amorphous wear phenomena (F), 67-68, 414-416
 delamination theory of wear (F), 67-68, 429, 433

Polymers, *continued*

- factors affecting friction and wear (F), 411-412, 426-427, 430-433
- fracture toughness (F), 428-429, 432
- friction forces (F), 419-426, 430-431
- hardness (F,T), 423, 424
- mechanical properties, comparative ranking of (F), 378, 379
- molecular structure (F), 412-414, 415, 427-431, 432-434
- morphology (F), 414-416, 421, 423-426, 427-430, 433, 434
- physical and mechanical properties (F,T), 416, 417, 418, 428-429, 432
- wear phenomena (F), 426-434
- wear resistance compared to that of metals and ceramics (F), 411-412, 435

Polypropylene (PP)

- friction coefficients (F), 420, 423-425, 427, 430
- intermolecular bonding (F), 414, 415
- mechanical properties (F), 417
- molecular structure and morphology (F), 413, 414, 415, 421, 423-425, 427, 428, 430, 431
- wear comparison to other polymers (F), 432
- wear mechanisms (F), 433

Polytetrafluorethylene (PTFE)

- friction coefficients (F), 423, 424
- molecular structure and morphology (F), 413, 423, 424, 425, 427, 428
- relation between friction and wear (F), 410, 426
- surface energy (T), 418
- wear comparison to other polymers (F), 426, 429-430, 431-433
- wear mechanisms (F), 433

Profilometry. *See* Surface profilometry

Prostheses, wear resistant materials for (F), 321-322, 324

Prow formation in adhesive wear (F), 239-240, 244, 386-387, 388, 389

Pure metals

- strain hardening behavior (F), 81, 82
- wear resistance vs. hardness (F), 88, 89, 90, 92

Pyrolytic decomposition coating processes (T), 359, 360

Quarrying equipment

- materials performance (T), 113, 383

Quartz abrasives (T), 94, 95 (*see also* Silicon dioxide)

Quenched and tempered steels

- abrasive wear resistance (F), 107
- strain hardening behavior (F), 82

- structure and microhardness profiles of friction layers (F), 401-403
- wear resistance vs. hardness (F), 88, 89, 90, 92

Rake angles of cutting tools, effect on chip generation (F), 26-29

Reactive evaporation coating processes, 363, 364, 367

Reactive sputtering, 364-365

Recrystallization

- during sliding wear (F), 120, 174, 179, 180, 282-284, 286, 287

- in copper shear band structures (F), 36, 37

Replica techniques of TEM, 269-271

Resolved shear stress in slip systems and friction calculations, 142, 144-147, 156, 183, 193

Retained austenite, effect on wear resistance (F), 106-108

Rock, abrasive action (F), 100, 101

Rolling, similarity of textures to sliding wear, 143-144, 148, 151, 176

Rolling contact fatigue as a wear mechanism (F), 22, 188, 226, 391-393

Roughness. *See* Micro-roughness; Surface roughnessRun-in. *See* Wearing-in

Sand particles in copper identified by TEM (F), 280, 281

Scanning electron microscopy

in-SEM experiments (F), 238-248

- use in wear research (F), 9, 236-248, 256, 258-263, 264, 266-268, 275

Scanning transmission electron microscopy, 273

Schmid factor in slip systems and friction calculations, 142, 145-150

SEM. *See* Scanning electron microscopy

Shear bands in deformation of wearing surfaces, 36-38, 84

Shear deformation

at asperity contact spots, 136

- in sliding (F), 120, 140, 141, 156-157, 182-184, 226-231

- leading to fracture mechanisms (F,T), 374-376, 387

Shear strain

- critical, for crack nucleation and propagation, 164-165

- development near sliding interfaces, 9-10, 17, 18, 126, 156-157

- distribution as determined from work hardening (F), 120, 170-176

- effects of flow stress, 140-142, 156,
170-176, 183-184
- in wear rate determinations (F), 164-168
- relation to tensile and true strains (F),
172-173, 174
- Shear strength (*see also* Low shear strength
films)
- correlation with friction coefficient as
function of temperature (F), 341-342,
343, 344
- in criteria for wear of plastics, 68
- Shear stresses (*see also* Resolved shear stress)
- at interface of hard coating to substrate, 357
- beneath indentations (F), 126, 130
- in fatigue theory of wear, 193, 200, 202
- in fracture mechanics calculations of wear
(F), 226-228
- in friction coefficient calculations, 140-142,
145-146, 156, 160, 336-339
- surface vs. subsurface (F), 142-143, 200, 202
- Silica (*see also* Silicon dioxide)
- production of coatings by pyrolytic decom-
position, 359
- Silica film replicas for copper, 269
- Silicates, frictional behavior (T), 338
- Silicon carbide abrasives (F), 86, 87, 88-92, 97,
98, 99, 306, 309, 311
- Silicon dioxide (*see also* Quartz abrasives;
Silica)
- abrasive wear surface (F), 90, 91
- Silicon nitride, abrasive wear surface (F),
91, 92
- Silver
- effect of temperature on correlation between
friction coefficient and tensile strength
(F), 341, 343
- friction and wear coefficients (F), 169
- production of coatings by pyrolytic decom-
position, 359
- Sliding behavior (*see also* Sliding wear
mechanisms)
- basic case of, 119, 120, 149-150
- break-in and steady-state stages (F), 4-5,
165, 193; 194, 212
- dry (F,T), 119, 120, 149-150, 248-269, 367
- in-SEM studies (F), 239-248
- modes of, 7
- of asperities (F), 17-19, 29, 31, 57, 58
- of polymers (F), 409-410, 426, 429, 431
- role of fatigue in (F,T), 187-219, 228, 232
- shear deformation in (F), 140, 141, 156-157,
182-184, 226-231
- similarity to wire drawing (F), 120, 143,
172-174, 175, 176-177, 184
- surface deformation and fracture (F), 35-38,
206
- surface texture geometry (F), 148
- Sliding direction
- definition (F), 8, 9
- effect on dislocation cell structure (F),
179-182
- effect on friction coefficient (F,T), 150-151,
423, 424
- Sliding distance
- effect on amount of damage (F), 193,
194-199, 200, 203, 212, 252-257
- effect on friction coefficient (F), 49, 50, 150,
252-257, 324
- effect on wear rate (F), 196-199, 212-213,
252-257
- effect on wear volume (F), 44, 165, 252-257
- Sliding speed
- effect on friction coefficient (F), 160-161,
162, 163, 346, 347, 422
- effect on wear rates (F), 170, 171
- temperature variations with, 161, 163, 170
- Sliding wear mechanisms (F), 13-41, 44, 245
(*see also* Sliding behavior)
- for low shear strength (solid lubricant) films,
331, 336-339, 350
- fracture mechanics in (F), 226-232
- Slip bands. *See* Microbands; Shear bands
- Slip-line field analysis (F), 17, 32-33, 52-54, 55
- Slip systems
- correlation with friction coefficient (F),
145-151
- dislocation cell formation in, 144-145
- effect on micro-roughness, 128-132, 133
- for low shear strength (solid lubricant) films,
331, 338-339, 350
- in wire drawing, 143
- Schmid factor and critical resolved shear
stresses, 142, 144-150
- surface vs. subsurface, 142-143
- S-N curves, similarity to lubricated wear curves
(F), 213-214
- Sodium, wear resistance of Triboloy 700 alloy
in (F), 320-321, 324
- Sodium chloride, effect on corrosive wear (F),
316-323
- Soft films. *See* Low shear strength films; Sur-
face films
- Soft surface layers, reasons for, 176
- Soils, abrasive action, 100
- Solid lubricants. *See* Low shear strength films;
Lubricants, solid
- Spalling of ball bearings (F), 393
- Specific heat of ceramics, effect on wear, 449
- Spherulitic structure of polymers (F), 415-416,
423, 425, 427, 428, 433
- Sputter cleaning, 364
- Sputtering processes (F), 363-365
- applications, 366, 367, 368
- D.C. and R.F. (F), 363, 364, 365, 367
- Stacking fault energy, correlation with friction
coefficient and slip systems, 143, 144, 149
- Stainless steels
- abrasive wear (F), 384

- Stainless steels, *continued*
 adhesive wear (F), 387
 coatings for wear resistance, 366, 367
 crack propagation in sliding wear (F), 230
 delamination wear (F), 392
 grooving energy (F), 407
 SEM and TEM micrographs of wear (F), 275
 structure and microhardness profiles of friction layers (F), 399, 400
- Standard case of dry sliding. *See* Basic case
- Stearates, lubricating effect on friction coefficient (T), 336, 337
- Steels
 abrasive wear examples (F), 381-384, 385
 abrasive wear performance data (T), 113
 adhesive wear (F,T), 384-390
 dry sliding wear studies (F,T), 248-269
 effect of carbide content on wear (F), 383-384, 385, 389
 effect of fracture toughness on wear resistance (F), 221, 222
 effect of structure, heat treatment and alloy content on wear resistance (F), 106-109
 effects of humidity and water on wear of (F), 301-302, 304, 305, 307-310, 312, 316, 317
 environmental effects on wear of (F), 293-294, 298, 299, 301-303, 305, 307-310, 312, 316, 317
 friction coefficient vs. sliding time using powder lubricant films (F), 340
 friction layers (F,T), 393-408
 hardness depth profiles (F), 79, 80, 393-408
 hardness of wear resistant coatings for, 352, 355
 hardness vs. wear resistance (F), 88, 89, 90, 92, 222, 223, 384
 lamellar wear particles (F), 17
 mechanical properties, comparative ranking of (F), 378-379
 mechanical properties as related to structure, 380
 microstructural changes during wear and fatigue, 204
 ribbon-shaped wear particles (F), 24-26
 strain hardening behavior (F), 81, 82
 structural effects on wear resistance, 380
 structure of friction layers (F), 395, 398-405, 406
 tough-brittle transition in (F,T), 378-379, 386
 wear mechanisms (F,T), 380-393
 wear resistance vs. hardness (F), 88, 89, 90, 92, 222, 223, 384
 wedge-shaped particles (F), 21
- Stereographic studies of wear, 236, 238
- Strain, effect on hardness profiles of friction layers (F,T), 394-398
- Strain distribution
 effect of work hardening (F), 120, 170-176
 in friction calculations, 156-157
 in groove formation (F), 77, 78, 124, 125, 126
 in subsurface areas (F), 200, 202, 204
- Strained surfaces
 plastic deformation, fracture and hardness (F,T), 77-81
- Strain-energy-density theory of crack growth.
See Minimum strain-energy-density theory
- Strain hardening (*see also* Work hardening)
 effect on wear phenomena (F,T), 77-81, 394-396
- Strain rate, effect of shear stress, 156-157, 170
- Strength criterion for crack nucleation. *See* Stress criterion
- Stress, interfacial, in crack nucleation, 61-62, 68
- Stress analysis, correlation with dislocation distribution (F), 126, 130
- Stress and strain distribution. *See* Strain distribution
- Stress criterion for crack nucleation (F), 62-63, 64, 65
- Stress intensity factor in crack propagation, 65, 66, 228, 451
- Striations (*see also* Fatigue striations)
 in microstructure of wear debris, 272
- Subgrains. *See* Grain structure
- Substrate fatigue theory (F), 193-198, 212
- Subsurface wear mechanisms (*see also* Deformed layer; Friction layers; Surface layers)
 fatigue theories (F), 199-205
 hardness depth effects (F), 200, 203
 linear elastic fracture mechanics in, 232
 methods of study, 8, 9, 236-237
 plastic deformation effect (F), 199-201, 202
 slip systems, 142-143
 stress and strain distributions (F), 200, 202, 204
 study by replica methods of transmission electron microscopy, 271
 study by thin foil methods of transmission electron microscopy, 274-276, 277
- Sulfates, frictional behavior (T), 338
- Sulfides, lubricating effect on frictional behavior (T), 337
- Surface coatings. *See* Coatings
- Surface energy
 effect on adhesive forces and surface roughness, 137-139
 effect on coefficient of friction of polymers (T), 419-423
 of polymers (F,T), 410, 411, 414, 416-418, 423, 426, 430, 431, 435
 of solid lubricants, 348, 350
 requirements for hard coatings, 355
- Surface films (*see also* Low shear strength films; Lubricants; Oxide films)

- effect on adhesive forces (F), 139, 151-154
 effect on friction coefficient (F,T), 151-155, 346-349
 lubrication effects (F,T), 151-152, 295-296, 335-350
 types affecting friction and wear, 119, 152-155
- Surface hardness. *See* Hardness; Hardness (coatings)
- Surface layers (*see also* Deformed layer; Friction layers; Surface films)
 development during wear (F), 375-377
 differences from bulk properties, 375-377
 examination by transmission electron microscopy (F), 274-286
 "fragmented" or micronized, 274
 polycrystalline (F), 274, 277, 279-285
 structural changes during wear (F), 35-38, 46-48, 232
- Surface modification treatments (T), 334, 355, 369
- Surface profilometry, 237, 252, 253
- Surface roughness (*see also* Micro-roughness)
 correlation with wear particle size (T), 207, 208, 209
 effect on adhesive forces, 137-140
 effect on friction coefficient (F), 57-58, 59, 349, 425
 effect on transmission and scanning electron microscopy, 271
 factors affecting (F), 128-132, 133
- Surfaces (*see also* Deformed layer; Strained surfaces; Subsurface wear mechanisms; Topography; Worn surfaces)
 characterization methods and studies (F,T), 235-289, 374-376
 deformation and fracture mechanisms (F), 35-38, 46-48, 77-81, 82, 232, 235-289, 375, 376
 effect of sliding wear on texture (F), 148
 stress/strain distribution at, 156-157
 study by transmission electron microscopy, 271
- Surface waviness
 effect of angle of inclination on adhesion, 138-139
- Surfacing, hard. *See* Hard coatings
- Tangential force (*see also* Friction forces)
 environmental effects on (F), 299, 302, 303-305
 in friction coefficient measurements, 325-326
- Taper sectioning, 236-237
- Teflon, as solid lubricant, 335, 341, 350
- TEM. *See* Transmission electron microscopy
- Temperature (*see also* Heat)
 critical, for transition from low to high wear rate (F), 311-312, 313
 effect on correlation between friction coefficient and tensile strength (F), 341-342, 343, 344
 effect on friction coefficient (F), 157, 158, 311-315, 316, 341-342, 420-422, 434
 effect on hardness profiles of friction layers (F,T), 394-398
 effect on mechanical properties of polymers (F), 416, 417, 418, 420
 effect on solid lubricant films (F), 341-342
 effect on wear of polymers (F), 426, 429, 430, 434
 effect on wear rate, 170
 environmental effects (F,T), 310-315, 316, 317
 measurement in wear tests, 7-8, 295
 variations at contact spot (F), 124, 155, 157-161, 323, 325
- Temperature, low
 effect on friction and wear (F), 312-313, 315-316
- Tensile forces in delamination crack propagation (F), 228, 229, 231
- Tensile strength. *See* Shear strength
- Terminology and definitions, 1-4, 38-40
- Testing equipment
 ball and cylinder configuration (F), 239-241
 block-on-ring configuration (F), 6, 7, 249-250, 258
 conforming and non-conforming geometries (F), 5, 6
 types of (F), 5-7
- Tests, experimental variables, 5-7
- Textures
 effect of slip systems (F), 142-144, 148
 effect on friction coefficient, 148-151
 rolling, 143-144, 148, 151
 surface (F), 35-38, 39, 148
 wire drawing, 143
- Thermal conductivity of polymers and metals (T), 416, 417, 418
- Thermal effects. *See* Heat; Temperature
- Thermal expansion
 as factor in coating material selection, 354
 effect on material removal volume in grinding, 448-449
- Thermocouples for wear testing, 8
- Thermodynamic properties as factor in coating material selection, 354
- Thermoplastic polymers. *See* Polymers
- Thermoplastics
 delamination theory of wear (F), 67, 429, 433
- Thickness (coatings)
 for surface treatments and hard coatings, 355-356, 358
 low shear strength films (F), 345-346, 347
- Thickness of deformed layer. *See* Deformed layer

- Thickness of wear particles. *See* Wear particles, thickness and volume
- Thin films. *See* Hard coatings; Surface films; Thickness (coatings)
- Thin foil methods of transmission electron microscopy (F), 237, 273-286
applications (F), 275, 277-287
- Thinning, for transmission electron microscopy (F), 275, 276
- Threshold force for lateral cracking. *See* Fracture threshold
- Threshold toughness/strength ratio. *See* Toughness/strength ratio
- Tin
as solid lubricant (low shear strength films) (F), 341
effect of surface roughness on friction coefficient (F), 349
effect of velocity on friction coefficient (F), 347
- Titanium
environmental effects on wear of, 300
friction coefficient vs. sliding velocity (F), 162
- Titanium alloys, structures of abraded surface, 47
- Titanium carbide, coatings of (F), 360, 366, 367, 368
- Tool steels
abrasive wear resistance (F), 108, 109, 381-384, 385
adhesive wear (F), 387, 388, 389-390
coatings for, 367
contact fatigue (F), 390, 391, 392
delamination wear (F), 392
dry sliding wear studies (F,T), 250-252, 256, 257, 263, 265
grooving energy (F), 407
shear fracture in (F), 376, 387
structure and microhardness profiles of friction layers (F), 401-404, 405
transmission electron microscopy, 270
- Topography (*see also* Surfaces)
examples of tribo-fracture (F), 375, 376
microscopy and stereographic study techniques (F), 237, 238-247
replica techniques for TEM examination, 269, 270, 271, 272
- Toughness (*see also* Fracture toughness)
correlation with grinding and machining forces for ceramics (F), 445-447
effect on wear rate of ceramics (F), 449-450
effect on wear resistance of steels (F,T), 378, 379, 380, 386
in lateral fracture model for wear of ceramics (T), 441, 442
relationship to other mechanical properties affecting wear resistance, 379-380
- Toughness/hardness relationships in wear mechanisms (F), 85-93, 103-105, 225-226, 227, 379, 380, 441-442, 446-447, 449-450
- Toughness/strength ratio in abrasive wear mechanism, 224-225
- Transmission electron microscopy
replica techniques, 269-271
thin-foil methods (F), 237, 273-284, 285, 286
use in wear research (F), 10, 236, 237, 269-287
- Tribaloy 700
wear resistance in nuclear reactor service (F), 320-321, 324
- Tribo-fracture mechanisms (F,T), 374-376, 380-381
- Tribological applications. *See* Applications of wear resistant materials
- Tribology (*see also* Sliding behavior)
history, 43, 188, 226
- Tribo-surfaces (*see also* Surfaces)
after fracture (F), 375-376
definition, 374
- Tribo-systems
block diagram (F), 377
definition and parameter groups (T), 374
friction layers in, 393
wear mechanisms, 374-375
- Tungstates, frictional behavior (T), 338
- Tungsten carbide/cobalt composite, abrasive wear resistance (F), 110-111
- Turbine engines, coatings for compressor blades, 366
- Twinning in wear surface and subsurface layers (F), 38, 39, 279, 281, 282
- Vacuum, wear measurements in (F), 298, 299, 306
- Vacuum coating processes (F), 362-365, 369
- Vacuum evaporation coating, 362-363
- Vapor deposition. *See* Chemical vapor deposition; Physical vapor deposition; Vacuum coating processes
- Void nucleation. *See* Crack nucleation and propagation
- Volume wear. *See* Wear volume
- Water (*see also* Aqueous environment; Humidity)
effect on abrasive wear rates (T), 93, 95
- Water vapor, environmental effects on wear (F,T), 93, 95, 291, 301-302
- Waviness. *See* Surface waviness
- Wear
definition and types of (F), 2, 38-40, 188, 189, 374
dislocation concepts in (F), 119-186
law of, 165, 190, 192, 212

- progressive behavior (F), 212, 213
- Wear coefficient**
 - correlation with friction coefficient (F), 168-169, 410-411, 426
 - determination for polymers, 426
 - determination of, 165, 168
 - effect of pH and ion concentration in aqueous solutions (F), 317-321
- Wear debris** (*see also* Microchips; Wear particles)
 - analysis and examination in wear studies (F), 14-15, 237-238, 240, 256, 258-265, 271-273
 - as indication of wear rate (F), 2-3
 - characterization methods and studies (F), 235-289
 - collection methods, 238, 249, 272
 - formation by plastic deformation and fracture, 84, 162-163
- Wear depth.** *See* Deformed layer, thickness
- Wear displacement.** *See* Deformed layer, thickness and area; Wear volume
- Wearing-in**
 - in-SEM studies (F), 238-248
 - mechanisms and theories (F), 161-170, 183, 212
- Wear mechanisms** (F,T), 38-40, 374-375, 380-381 (*see also* Abrasion mechanism of wear; Adhesion theory of wear; Corrosive wear; Delamination theory of wear; Fatigue theories of wear; Micro-roughness, in models for friction and wear; Sliding wear mechanisms)
 - for ceramics (F,T), 439-452
 - for polymers (F), 426-434
 - for steels (F,T), 380-393, 406-407
- Wear particles** (*see also* Wear debris)
 - chip-like (F), 25-29
 - classification, 15-16
 - correlation of size with surface roughness (T), 207, 208, 209
 - formation (F), 206-210
 - formed by delamination (F), 45, 46, 60, 61, 65, 67
 - in adhesion theory of wear (F), 188-189, 190
 - irregular-shaped (F), 29-34
 - laminar (F), 16-20, 21, 84
 - microstructure, examination by TEM (F), 272-273
 - morphology (F), 16-35, 256, 258-265, 272, 273
 - oxide (F), 34-35
 - plate-shaped (F), 16-22, 238, 245
 - ribbon-shaped (F), 24-29, 244-245, 247
 - rubbing type (F), 189, 190
 - sampling, 15
 - scanning electron microscopy (F), 240, 243, 244, 247, 256, 258-263, 264, 265
 - sheet-like (F), 45, 46, 60, 61, 65, 67
 - size and shape (F), 240, 244, 245, 258-260, 263, 264, 265, 268
 - size distribution (F), 206, 207, 208
 - size vs. thickness of deformed layer (F), 207-208, 209
 - sources of, 162-164
 - spherical (F), 22-24
 - splintery (F), 24
 - thickness and volume in wear rate determinations, 164-168
 - transmission electron microscopy (F), 269, 271-273
 - wedge-shaped (F), 20-22
- Wear rate** (*see also* Wear coefficient)
 - calculations of, 161-170, 171, 351-352
 - changes studied by TEM, 270
 - control by delamination mechanisms, 60
 - correlation with fatigue resistance (F), 213-217
 - correlation with friction coefficient (T), 161-162, 252-257, 268, 326
 - definition, 3-4
 - effect of atmospheric pressure (F), 214-217
 - effect of cold work (F), 214, 215
 - effect of crack propagation (F), 64, 65
 - effect of fracture toughness (F), 225-226, 227, 428-429, 432
 - effect of internal stress (F), 213-214
 - effect of oxygen partial pressure (F), 296, 297, 298, 326
 - effect of sliding distance (F), 196-199, 212-213, 252-257
 - effect of sliding speed (F), 170, 171
 - effect of temperature (F), 170, 310-314, 426, 429
 - environmental effects on (F), 292, 296, 297, 298, 302, 306, 307, 309, 311
 - material displacement vs. weight or volume loss as indicator (F), 2-3
 - model for oxidational theory, 294-295
 - of ceramics, comparison to metals and polymers (F), 411-412
 - of ceramics, determination, 443, 444, 449-450
 - of ceramics, effect of hardness and toughness (F), 449-450
 - of ceramics, fracture threshold effects, 440, 441, 449
 - of metals, comparison to polymers and ceramics (F), 411-412, 435
 - of polymers, as related to friction coefficient (F), 410-411, 426-427, 431-433
 - of polymers, comparison to metals and ceramics (F), 411-412, 435
 - of polymers, determination (F), 426-429
 - quantitative relationships, 164-170
 - reduction by hard coatings, 351
 - similarity to S-N curve in fatigue testing (F), 213-214

- Wear rate, *continued*
 steady-state vs. incubation period, 165
 variations in steady state (F), 198, 199
- Wear research and development, 13-15 (*see also* Tribology, history)
 methods of study, 322-326
- Wear resistance. *See* Wear rate; *various types of wear*
- Wear scars (*see also* Deformed layer; Wear tracks)
 effect of humidity and water on area and depth (F), 302, 306, 307-310, 316, 317
 events leading to (F), 238-248
 methods of formation (F), 2-3
- Wear spot. *See* Wear scars
- Wear surfaces. *See* Worn surfaces
- Wear tests. *See* Testing equipment; Tests
- Wear tracks (*see also* Groove formation; Plowing; Wear scars)
 microtopography studies (F), 238-248
 morphology (F), 238-248, 258, 261, 262, 266-268
- Wear types, classification (F), 4, 38-39, 188, 189
- Wear volume
 as function of sliding distance (F), 44, 252-257
 calculation of (F), 14, 28, 76-77, 85, 87-93
 correlation with thickness of deformed layer (F,T), 207-208, 209, 252-257
 effect of crack propagation rate, 66-67
 effect of temperature (F), 314, 317
 in wear rate calculations, 165-168
 vs. wear depth and friction coefficient for steels (F,T), 252-257
- Welded asperity junctions. *See* Adhesion theory of wear; Asperities; Asperity contact spots
- Wire drawing
 similarity to sliding wear (F), 120, 143, 172-174, 175, 176, 177, 184
 slip systems in, 143, 172
- Work-hardened surfaces, fracture during sliding (F), 33-34
- Work hardening (*see also* Strain hardening)
 by plastic deformation at indentations, 137
 effect on shear strain distribution (F), 120, 170-176, 177
- Work hardening law, 120, 173, 175-176
- Work softening, 175-176
- Worn surfaces (*see also* Surfaces)
 cross sections of (F), 8, 9
 examination and characterization (F,T), 235-289, 376-377
 fatigue striations on (F), 210, 211
 friction layers of (F,T), 393-408
 hardness/wear relationships (F,T), 100-105, 393-398
 mechanical properties (F), 100-105
 plastic deformation effects (F,T), 77-81, 82
 study by electron microscopy (F), 235-289
 structure (F), 35-38, 39, 239-245, 246, 247, 258, 261, 262, 266-268, 398-406
- Yield strength/toughness ratio. *See* Toughness/strength ratio
- Yield stress (*see also* Stress, interfacial)
 comparative ranking for various materials (F), 378, 379
- Young's modulus. *See* Elastic modulus