## Index

| A   | aging, 385   |
|---|--|
| A/B petrol and diesel engine, 233, 234 (table), 235                           | accelerated, 388–390, 388 (figure), 389 (figure)               |
| (table), 236 (table)  | limits, 410, 411 (figure)                                      |
| ABDT. See sealed bearing simulation tester                                    | See also accelerated aging tests; oxidative stability          |
| ABFT. See accelerated life tester (ABFT)                                      | air retention, 284   |
| abnormal sound, 144, 146, 148 (table)   | air-fuel ratio, 122–123  |
| abrasive wear, 296–299, 298 (figure)  | alignment errors, 382–383                                      |
| abuse testing, 289  | alkalinity, 404, 415   |
| accelerated aging test, 388–390, 388 (figure), 389 (figure)                   | all-wheel drive, 160 (figure), 164                             |
| accelerated life tester (ABFT), 149-150, 149 (figure), 150                    | Al-Si alloy, 338–339, 355 (figure), 364 (figure), 368–375      |
| (figure), 151 (figure)  | alternative fluids, 320–321, 328–329                           |
| accelerated tests, 146, 276-277, 388-390, 388 (figure),                       | film forming and, 321–324                                      |
| 389 (figure)  | fuel, 82, 218, 228–229   |
| ACEA C (X), 82, 233   | shear thinning and, 323-324                                    |
| ACEA C4-08, 75, 76, 77, 78  | wear tests and, 323-328  |
| ACEA E (X), 233–237, 238 (table), 239 (table)                                 | See also biofuel; vegetable oil                                |
| ACEA E9-08, 68-69, 70, 71, 72, 74, 78-79                                      | aluminizing, 335   |
| ACEA Heavy-Duty Diesel (HDD), 232-233, 241 (table),                           | aluminum, 335, 340. See also aluminum alloy                    |
| 241–242   | aluminum alloy, 107, 108, 109, 125, 215, 338, 407              |
| ACEA performance standards, 34, 36, 233-237, 234                              | Aluminum Beaker Oxidation Test (ABOT), 266                     |
| (table), 235 (table), 236 (table). See also European                          | aluminum oxide, 227–228  |
| Automobile Manufacturers' Association (ACEA);                                 | American Chemistry Council Product Approval Code of            |
| specific standards  | Practice, 227  |
| acid number (AN), 404, 412, 413   | American Oil Chemist Society (AOCS), 460                       |
| acids, 206, 429–430   | American Petroleum Institute (API), 64, 68, 226. See also      |
| acrylonitrile/butadiene/styrene (ABS), 383 (figure)                           | API performance standards; specific standards                  |
| additive company, 259   | American Society for Testing and Materials (ASTM),             |
| additives, 23, 34-35, 111, 200 (table), 207 (table), 252,                     | 64, 217, 226, 231. See also ASTM test methods;                 |
| 353, 368–369, 413 (figure)  | performance standard, organizations; specific test             |
| alternative depletion, 413  | methods  |
| antiwear, 29 (figure), 29–30, 48, 108, 198–201, 202,                          | ammonia (NH <sub>3</sub> ), 127, 209                           |
| 209, 220, 224, 247, 368–371, 369 (figure), 370                                | angular velocity, 122, 123                                     |
| (figure), 371 (figure)  | anhydrous ethanol, 419 (table)                                 |
| atomic force microscopy (AFM) and, 358 (figure)                               | antifoam agents, 26, 48, 200 (table). See also foam            |
| bulk fluid property, 261  | control  |
| detergents, 31, 33 (figure), 34 (table)                                       | antioxidant, 26–27, 27 (figure), 48, 200 (table)               |
| dispersants, 30–33, 298   | antioxidant reserve test, 71                                   |
| friction and, 22, 29, (figure), 224, 352, 362 (figure), 369                   | antitrust agent, 200 (table)                                   |
| (figure), 371–372, 371 (figure), 372 (figure)                                 | antiwear agent, 29–30, 29 (figure), 31 (table), 48, 200        |
| extreme pressure and, 30, 31 (table), 261                                     | (table), 333–337, 338–345. See also additives, antiwear        |
| fuel and, 317–318, 321, 325   | APEA performance requirements, 36                              |
| functions, 198–201  | API basestock classification system, 47, 48 (table)            |
| gears and, 170  | API C series specifications, 240–241. See also specific        |
| grease, 41  | specifications   |
| lubricity and, 417–418, 423   | API C (X), 242–243   |
| protective, 27–28, 29 (figure), 261   | API CI-4, 36, 68, 232–233                                      |
| performance, 23–26, 261   | engine tests, 72–74, 241 (table)                               |
| soot and, 298   | laboratory tests and, 70–72                                    |
| surface analytical techniques and, 367–368                                    | API CJ-4, 243 (table)  |
| transmissions and, 262–266<br>tribology and, 319–332, 347–348, 369–372        | API GL 4 191 288   |
|   | API GL-4, 181, 288   |
| viscosity modification and, 111  See also molybdenum dithiocarbamate (MoDTC); | API GL-5, 181, 288 See also ILSAC GL-5                         |
| specific additives; specific components; specific                             | API performance standards, 34, 36. See also specific standards |
| materials; zimc dialkyl dithiophosphate ZDDP                                  | API S (X), 243–244, 245 (table)                                |
| adhesive wear, 296, 298 (figure)  | API SM, 243–244, 245 (table), 246 (table)                      |
| A/8.3/90, 180, 181  | API SN, 245, 249 (table)                                       |
| 1110.3170, 100, 101   | 111 1 OIX, 273, 277 (table)                                    |

481

|   | 1   |
|---|---|
| API Tripartide Sequences, 237–244. See also specific        | bearing, 109 (figure), 131 (figure), 132–133, 134, 168    |
| sequences   | auxiliary, 142  |
| API Tripartite System, 64–65, 82                            | ball, 153 (table)   |
| aromatic base oil, 261                                      | damage and, 77, 134–135                                   |
| ash, 247, 250 (table). See also soot                        | electrical part, 142                                      |
| ashless dispersants, 47                                     | grease and, 42  |
| Asia, 259   | hub, 137–139, 138 (table), 139 (figure)                   |
| asperities, 3, 5 (figure), 7–8, 120                         | inserts, 107–108  |
|   |   |
| asperity contact model, 18                                  | journal, 18, 19, 129–132, 130 (figure), 131 (figure)      |
| Association for Petroleum and Explosives                    | material for, 132–133, 382, 395–396                       |
| Administration (APEA). See APEA performance                 | non-automotive, 379 (figure)                              |
| standards; <i>specific standards</i>                        | shells, 130 (figure), 131, 134 (figure)                   |
| ASTM test methods, 290–291, 420 (table), 421. See also      | sliding, 106  |
| specific test methods                                       | speed, 262  |
| ASTM Wear and Erosion Terminology Standard                  | surface treatment and, 133                                |
| G-40, 420   | temperature and, 129                                      |
| atom force microscopy (AFM), 357–358, 357 (figure),         | See also bearing design; bearing tests; specific          |
| 358 (figure), 359 (figure), 371 (figure)                    | bearings  |
| atomic emission spectroscopy, 408                           | bearing tests, 133–134, 134 (figure), 146–154. See also   |
| 1 10  | bearing vibration tests                                   |
| ATR FTIR spectrometer, 366 (figure), 367 (figure)           |   |
| ATR tribometer, 367   | bearing vibration test (BVT), 144–146. See also bearing   |
| attenuated total reflection (ATR) spectroscopy, 366         | vibration tester  |
| attenuation, 385  | bearing vibration tester, 144–146, 144 (figure), 145      |
| Auger electron spectroscopy (AES), 361                      | (figure, 146 (table), 147 (table)                         |
| autocorrelation function, 5                                 | Beilby layer, 3   |
| automatic dinematic viscometer, 49                          | belt arrangement, 259 (figure)                            |
| automatic transmission fluid (ATF), 37, 255, 261 (table),   | bench scuffing wear simulation test, 98                   |
| 266–267   | bench test rigs, 97, 178                                  |
| chemical construction of, 259–266                           | bench tests, 94, 96 (table), 99 (table), 111–114, 134     |
| planetary gear and, 257                                     | (figure), 287   |
| automotive bearing vibration. See bearing vibration test    | alternative fuel and, 218, 228–229                        |
| automotive exterior, 381                                    | API CJ-4, 195–197 (table), 199 (table)                    |
|   |   |
| automotive fluid test. See specific lubricants; specific    | cylinder components and, 218–219, 223–224                 |
| standards; specific tests                                   | diesel fuel and, 420                                      |
| automotive gear oil tests, 38, 39 (table)                   | friction and, 393 (figure)                                |
| automotive grease. See grease                               | ILSAC GF-5 and, 248–249 (table)                           |
| automotive service grease, 43-45, 137-138. See also         | industrial standards and, 95                              |
| grease  | material and, 215, 216 (figure), 216-218, 217 (table),    |
| auxiliary engine parts, 142 (table), 143 (table)            | 218 (figure), 226   |
| average Reynolds equation. See Reynolds equation            | pistons and, 218-219, 220-223                             |
| aviation fuel, 417  | test method and, 97–98. See specific methods              |
| AW agent, 263–264, 318                                      | valve train subsystems and, 218–219                       |
| axle, 36, 38, 159–160, 165 (figure), 166 (figure). See also | See also laboratory tests; specific tests; tribological   |
| axle, 30, 30, 137–100, 103 (figure), 100 (figure). See also | bench tests   |
|   |   |
| axel lubricant, 288   | biofuel, 82, 209, 232, 237, 253–254. See also alternative |
| axle fluid, 38–39, 38 (table)                               | fluid; vegetable oil                                      |
| axle tests, 288   | bio-no-tox, 317, 318, 319. See also alternative fluid;    |
|   | biofuel   |
| В   | black sludge test, 78                                     |
| ball bearing, 153 (table)                                   | block wear, 97  |
| ball joint, 140   | block-on-ring tester, 218 (figure)                        |
| Ball Rust Test (BRT), 81, 112, 193 (table), 226             | Blok's solution, 15                                       |
| BAM test, 325–326   | blotter spot testing, 410                                 |
| band clutches, 256–257, 257 (figure)                        | BOCLE (Ball-on-Cylinder Lubricity Evaluator), 420         |
| base number (BN) test, 413                                  | bore shape, 131   |
|   |   |
| base oil, 23, 24 (figure), 35 (table), 111, 317             | boriding treatment, 335                                   |
| grease and, 142   | boundary film, 19, 204                                    |
| transmission fluid and, 259–261, 260 (figure), 260          | boundary friction coefficient, 206. See also friction     |
| (table)   | coefficient   |
| See also basestock  | boundary lubrication, 19, 204, 263, 301, 352, 353         |
| basestock, 47, 260 (table). See also base oil               | (figure). See also specific systems                       |
| bathtub curve, 62   | Boussinesq equation, 6–7, 14                              |

AST-MNL62-12-0501-IND.indd 482 01/10/12 6:57 PM

| brake mechanisms, 42, 346-347, 380  | computer models, 284  |
|---|---|
| breathers, 284  | conformal contact, 5, 18–19   |
| bridge phenomena, 208   | conformal engine, 19  |
| bridging oxygen (BO), 370   | connecting rod, 125–126   |
| bulk oil, 261–262   | constant velocity (CV) joint, 421, 437–439, 445 (figure)                          |
| buried surface, 366–367   | apparatus, 438–439  |
| bypass oil filters, 427, 429, 434   | friction characterization and, 442-446  |
|   | friction coefficient and, 440–441, 440 (figure), 441                              |
| С   | (figure), 443 (figure), 444 (figure), 446–448, 447                                |
| calcium, 139  | (figure), 448 (figure), 449 (figure), 450, 452 (figure)                           |
| cam and follower, 352–353, 353 (figure)                                     | friction measurement and, 439–442, 442 (figure),                                  |
| cam follower system, 219, 220, 345  | 438, 439 (figure)   |
| Cameron-Plint high frequency friction machine, 96, 97                       | friction modeling, 446–452, 452 (figure)  |
| (figure), 97–98, 219 (figure)   | grease and, 140–142, 141 (figure)   |
| camshaft, 108–109, 223  | contact analysis, 5–9, 217 (figure), 302–304. See also specific engine components |
| camshaft tests, 223–225, 224 (figure)<br>capacitance method, 85             | contact mechanics, 302, 304, 303 (figure). See also                               |
| carbon, 334, 335  | specific mechanisms   |
| carbon monoxide (CO), 126   | contact pressure, 217 (table)   |
| carbon polymer tails, 31 (figure)   | contaminant capacity, 435   |
| carbonitriding, 335   | contamination, 23, 205, 384, 402, 409 (figure)                                    |
| carburizing, 64, 334  | moisture and, 412–413   |
| cast iron, 125, 245, 338, 340, 342, 407                                     | filtration and, 429–430, 429 (figure), 435  |
| Castrol. See Greentec LS 5W-30  | solid particle, 411–412   |
| catalytic converter, 78, 127, 128 (figure), 209                             | continuous oil recycling system, 461, 463, 462 (table)                            |
| Caterpillar C13, 195 (table), 198, 199, 242 (table)                         | continuously slipping torque converter clutches                                   |
| Caterpillar 1N, 74, 195 (table), 198, 199, 242 (table)                      | (CSTCCs), 257   |
| CCMC (Comite des Constructeurs du Marché                                    | continuously variable transmission (CVT), 258–259, 259                            |
| Commun), 65   | (figure)  |
| centerline average, 4, 16 (figure)  | continuously variable transmission (CVT) fluid, 37,                               |
| ceramic material, 342, 344  | 258–259   |
| C-GFKT/8.3/90, 184  | cooling circuit, 126. See also continuously variable                              |
| chassis system, 43–44   | transmission (CVT) fluid  |
| chemical bond vibrational techniques, 360                                   | cooling tests, 277–278  |
| chemical limits, 71–72, 241 (table), 242                                    | Coordinating European Council for the Development                                 |
| chemical properties, 360–367, 360 (figure)                                  | of Performance Tests for Transportation Fuels,                                    |
| chemically inert additive, 41   | Lubricants, and Other Fluids (CEC), 65–66   |
| Chevron Test, 181   | copper alloy, 407   |
| chlorine, 82  | copper corrosion inhibitor, 264, 265  |
| chromium, 335, 342, 344   | Cooper Strip Corrosion Standard, 56   |
| Chryslet, 266–267   | CORES converter, 462 (figure), 462–463  |
| CI compounds, 30  | corporate average fuel economy (CAFE), 201, 254                                   |
| circular point contact, 302 (figure), 302–303                               | corrosion, 56, 300, 385 (figure), 391 (figure)                                    |
| CJ-4. See API CJ-4  | corrosion inhibitor, 33, 200 (table), 264–265, 265 (figure)                       |
| Cleveland open cup (COC), 56  | corrosive wear, 300   |
| clip ratio, 443 (figure)  | counterformal contact, 5, 18  |
| closed loop testing, 276  | counterformal engine, 19  |
| cloud point, 52<br>clutch friction specifications, 251 (table), 252 (table) | coupling greases, 43  |
| clutch, 251 (table), 252 (table), 262, 346, 356 (figure)                    | course filtration, 428 crackle test, 410  |
| coated surfaces, 8–9. See also specific surfaces                            | crank angle, 121–122, 131   |
| cold crank simulator (CCS), 49, 80  | crankcase lubricants, 199 (table)   |
| cold-scuffing, 221, 225–227, 226 (table), 227 (table)                       | cranking viscosity, 49–50   |
| cold-start simulation, 435  | crankshaft, 105, 106, 107–108, 121, 125   |
| collapse test, 435  | crankshaft-rod-piston connecting system, 124                                      |
| color, 56   | CrC-NiCr coating, 342   |
| colorimetric interferometry technique, 86                                   | CrN coating material, 339   |
| combustion, 105, 106, 119   | C-type gears (C-PT), 185 (figure), 186, 187                                       |
| commercial engine, 43, 119  | Cu, 33–34   |
| combustion engine architecture, 124   | Cummins Bearing Corrosion Test and the Corrosion                                  |
| compression, 105, 119, 120  | Bench Test (CBT), 56, 73  |
| compression ring 341 342  | Cummins fuel injector, 418 (figure)   |

AST-MNL62-12-0501-IND.indd 483 01/10/12 6:57 PM

|  | 770/0 7/   |
|--|--|
| Cummins ISB, 195 (table), 198, 199, 242 (table)            | D5968, 56  |
| Cummins ISM, 195 (table), 198, 199, 237, 242 (table)       | D5985, 52  |
| Cummins M-11, 299  | D6082, 53, 193 (table)   |
| cumulative distribution function, 4                        | D6278, 52  |
| cumulative plastic deformation, 110                        | D6335, 57  |
| CVD, 336   | D6417, 53, 192 (table)   |
| cylinder, 105, 120, 124–128                                | D6425, 286 (table)   |
| elastic, 6   | D6557, 193 (table)   |
| materials and, 339 (figure), 339-340, 347 (table)          | D6593, 192 (table), 194  |
| multi-, 124, 125   | D6594, 56  |
| See also combustion engine architecture                    | D665, 286 (table)  |
| cylinder bore, 108, 338–339. See also cylinder bore tests  | D6709, 51, 52, 80, 192 (table). See also Sequence VIII           |
| cylinder bore tests, 218–219, 220–223, 224 (figure), 225   | D6749, 52  |
| (figure)   | D6794, 56–57, 193 (table)  |
| cylinder liner tests, 223–224, 319, 347                    | D6795, 56, 193 (table)   |
| C/0.05/120/12, 182   | D6821, 51  |
| C/0.05/90/12, 182  | D6837, 194   |
|  | D6891, 77, 192 (table), 194. See also Sequence IVA               |
| D  | D6892, 52  |
| D1217, 55  | D6894, 53–54, 71 (table)   |
| D130, 56   | D6895, 51  |
| D1480, 55  | D6896, 70 (table)  |
| D1481, 55  | D6922, 81, 193 (table)   |
| D1500, 56  | D6984, 74  |
| D2240, 193 (table), 194 (table)                            | D7038, 288   |
| D2266, 286 (table)   | D7097, 57, 192 (table)   |
| D2500, 52  | D7109, 69  |
| D2603, 52  | D7146, 197   |
| D2782, 286 (table)   | D7156, 70 (table)  |
| D2893, 286 (table)   | D7216, 57  |
| D2983, 51  | D7320, 76, 192 (table). See also Sequence III-GB                 |
| D3427, 286 (table)   | D7450, 39 (table), 43, 288                                       |
| D3527, 286 (table)   | D7452, 288   |
| D4052, 55  | D7528, 193 (table)   |
| D412, 193 (table), 194 (table)                             | D7563, 193 (table)   |
| D4289, 286 (table)   | D7589, 192 (table). See also Sequence VID                        |
| D445, 49   | D8696, 197   |
| D4485, 49  | D874, 55, 71 (table)   |
| D4624, 323   | D892, 53, 71, 193 (table), 286 (table)                           |
| D4683, 68, 69–70, 238, 232                                 | D97, 52  |
| D4684, 51, 238   | damage accumulation, 110   |
| D471, 193 (table), 194 (table)                             | deep-groove ball bearings, 153 (table), 167                      |
| D4741, 323   | deformations, 6–7, 7 (figure), 302                               |
| D4857, 252   | degradation, 61–63, 62 (figure), 207                             |
| D4858, 252   | biodiesel and, 237   |
| D4863, 252   | performance specifications and, 63-66                            |
| D4950, 139 (table), 140 (table), 464 (table), 466–467, 466 | testing and, 66–67   |
| (table)  | demulsifiers, 200 (table)  |
| D4951, 54, 71 (table), 192 (table)                         | density, 11, 55  |
| D4998, 181   | density-pressure relationship, 11, 13                            |
| D5133, 50, 51, 192 (table)                                 | deposits, 73–74, 76, 79, 206, 237                                |
| D5158, 54–55   | design life, 274   |
| D5183, 286   | design tools, 313  |
| D5275, 51, 52  | detergents, 31, 33 (figure), 34 (figure), 47–48, 206, 263,       |
| D5579, 288   | 264 (figure)   |
| D5662, 57  | deterministic modeling, 15, 18                                   |
| D5704, 287 (table)   | DEXRON®, 266, 267 (table)  |
| D5706, 324–325, 326 (figure)                               | DI package, 47   |
| D5800, 53, 71, 192 (table)                                 | diamond-like carbon (DLC) coating, 97, 133, 224                  |
| D5949, 52  | diesel catalyzed particle filters (DCPF), 209–210                |
| D5950, 52  | diesel engine oil, 194, 197. <i>See also</i> diesel engine tests |
| D5966, 74  | diesel engine tests, 194, 195–197 (table), 197–198               |
|  |  |

AST-MNL62-12-0501-IND.indd 484 01/10/12 6:57 PM

| diesel engine  | efficiency standards. See performance standards              |
|--|--|
| emissions control and, 127-128                             | efficiency test, 186–188, 187 (figure), 282–284, 283         |
| lubrication, 231–232, 232 (figure)                         | (table)  |
| material and, 372  | elasohydrodynamics lubrication film tests, 85, 87            |
| pistons and, 340   | (figure), 91 (figure), 92 (figure), 92 (table), 93 (figure), |
| powertrain and, 120, 122–124, 123 (figure)                 | 94 (figure), 101–102   |
| See also A/B petrol and diesel engine; diesel fuel         | fluid behavior and, 87-88                                    |
| diesel fuel, 68, 75, 120, 417–423, 418 (figure)            | measurement techniques and, 85-87                            |
| fuel filters and, 432–433                                  | surface lubrication and, 89-90, 89 (figure),                 |
| sulfur in, 239–240   | 91–93  |
| See also biofuel; ethanol-diesel; vegetable oil            | thickness and, 85–87, 87 (figure)                            |
| diesel ideal cycles, 120 (figure)                          | See specific techniques                                      |
| diesel particulate filters (DPFs), 127-128, 231            | elastic cylinders, 6   |
| differential, 282  | elastohydrodynamic contact, 86                               |
| differential assembly, 167 (figure)                        | elastohydrodynamic lubrication, 13, 14, 15, 301              |
| differential pressure, 434, 435                            | Elastomer Compatibility Test, 209                            |
| diffuse reflectance infrared Fourier transform (DRIFT)     | elastomer, 57, 81 (table), 115, 193 (table)                  |
| spectroscopy, 209  | elasto-plastic contact, 9                                    |
| dimethylopolysiloxanes, 386                                | elastoviscious effect, 10                                    |
| DIN 51819, 151–152   | electic motors, 379  |
| Direct Injection Diesel Poston Cleanliness and Ring        | electrical contact switch, 42                                |
| Sticking test, 72, 78                                      | electrical part bearings, 142 (table), 143 (table), 143-144  |
| discharge-voltage method, 85                               | (figure)   |
| dispersant, 30–33, 31 (figure), 32 (figure), 33, (figure), | electrochemical coating, 335                                 |
| 34 (table), 47, 263 (figure), 298; ashless, 47             | elemental spectroscopy, 409-410, 412, 413, 414               |
| dispersant viscosity modifier (DVM), 31                    | elements, 54, 409 (figure). See specific elements            |
| displacement, 105, 121, 122, 359 (figure), 360 (figure)    | elliptical contact. See point contact                        |
| distribution system, 126                                   | embedability, 107  |
| Doolittle parameter, 10                                    | EMCO rust test, 139  |
| door hinges, 42  | emissions, 71–72, 318  |
| Dowson-Higgison's solution, 15                             | diesel, 417  |
| drain port sampling, 400                                   | particulate, 231   |
| drive bearings, accessory, 42                              | regulation of, 61–62, 126–127, 227, 231, 253                 |
| drive gears, 281   | improvements, 110  |
| drive units. See final drive units                         | See also environmental effect                                |
| driveline. See drivetrain                                  | emulsion retention test, 81                                  |
| driveline fluid, 35–38, 39 (table)                         | energy dispersive x-ray (EDX), 360–361, 361 (figure)         |
| driveshaft, 42, 165-166, 285, 286 (table), 437             | engine, 105, 119, 124, 352 (figure)                          |
| drivetrain, 157–160, 158 (figure), 171–175, 345–347.       | block, 125, 372  |
| See also drivetrain tests; gear box; transmission          | characterization, 105-106, 351                               |
| drivetrain tests, 275–279. See also transmission;          | components of, 215, 338-345, 379-382, 379 (figure),          |
| transmission tests   | 380 (figure), 381 (figure), 382 (figure), 385 (figure)       |
| drop-tube vacuum sampling, 400–401 (figure)                | friction loss and, 351–352                                   |
| dual clutch gear box, 164                                  | non-automotive, 252–253                                      |
| dual-clutch transmission (DCTs), 258–259, 259 (figure).    | See also engine material; heavy-duty diesel; internal        |
| See also dual-clutch transmission (DCT) fluid              | combustion engine; passenger cars; specific                  |
| dual-clutch transmission (DCT) fluid, 37, 258              | components; specific engines; triboactive material           |
| durability tests, 275-276, 328 (figure). See also specific | engine architecture, 124                                     |
| tests  | engine bearing. See bearings                                 |
| dustproof head test, 148, 149 (figure)                     | engine block, 125, 372                                       |
| dynamic friction model, 448-449, 449 (figure), 448-449,    | engine deposits. See deposits                                |
| 452 (figure)   | engine dynamometer test, 98                                  |
| dynamic viscosity, 49                                      | engine material, 106, 107, 110, 333, 372–375                 |
| dynamometer, 225, 309, 463                                 | behavior, 336 (table),390-391, 390 (figure), 427             |
|  | candidate, 217 (table)                                       |
| E  | follower, 220, 222 (figure)                                  |
| E1078, 361   | polymer, 382–383   |
| E1829, 361   | precision mechanics and, 382                                 |
| E1840, 367   | Engine Oil Aeration Test (EOAT), 53–54, 71 (table), 195      |
| E2695, 365   | (table), 197–198. See also ASTM D6894                        |
| E6-03. See ACEA E6-08                                      | Engine Oil Licensing Certification System (EOLCS),           |
| e-diesel. See ethanol-diesel                               | 64–65  |

AST-MNL62-12-0501-IND.indd 485 01/10/12 6:57 PM

| engine oil, 34–35, 34 (figure), 35 (figure), 36 (figure), 207–209, 318 (figure), 410–411 | European Automobile Manufacturers' Association (ACEA), 65–66, 68, 232. <i>See also</i> European perfor- |
|--|---|
| additives and, 368. See also additives   | mance standards; specific standards   |
| aeration, 242 (table)  | European performance standards, 62, 64, 65–66, 67,  |
| alternative, 320 (table), 320-321, 461-465   | 232–237, 234 (table), 235 (table), 236 (table). See also  |
| analysis of, 401–410, 411–415, 411 (figure), 414   | specific ACEA standards   |
| (figure)   | evaporation behavior, 388   |
| compression band, 108  | exhaust, 105  |
| diesel, 194, 197   | exhaust gas recirculation (EGR), 73, 127, 194-195, 195  |
| gear boxes and, 162, 163   | (table), 197, 198, 206, 209–210, 231, 297–298   |
| precision mechanics and, 384–391, 387 (figure), 388                                      | extended service intervals, 254   |
| (figure)   | extended x-ray absorption fine structure (EXAFS), 362   |
| specifications and, 318–319, 323 (table)   | extreme operating conditions, 278–279   |
| tests, 38, 39 (table)  | extreme pressure (EP) agent, 30, 31 (table), 200 (table),   |
| See also alternative fluids; oil; oil filter; oil sampling                               | 201, 263–264, 318, 324–325  |
| methods; specific engine types; specific oils  | Eyring-Ewell equation, 9  |
| engine seal. See seal  |   |
| engine tests, 36, 62, 64–65, 66–67, 111, 225–226   | F   |
| accelerated, 66, 388-390, 388 (figure), 389 (figure)                                     | factory-fill hydrocarbon based oil, 320-321   |
| ACEA C and, 36 (table), 133, 236 (table)   | FAG FE8, 151, 152 (figure)  |
| API CJ-4 and, 36 (table), 195-197 (table), 199 (table)                                   | FAG FE9, 152 (figure)   |
| alternative fluid and, 323–328   | Falex BOTS, 420   |
| bearings and, 144–154  | Falex-type block-on-ring friction and wear tester, 96, 97   |
| biobased lubricants and, 461-464. See also biobased                                      | (figure), 218 (figure)  |
| lubricant; specific test methods   | Farm Bill, 456  |
| gear oil and, 38, 39 (table)   | fatigue life, 149–150, 150 (table), 153 (table)   |
| grease and, 44 (table)   | fatty acid methyl esters (FAMEs), 209, 237  |
| performance specifications and, 61, 62 (figure),   | fatty acids, 459  |
| 62–63  | ferrography, 406 (figure), 412. See also ferrous density  |
| precision mechanics parts and, 392–398, 392 (figure).                                    | ferromolybdenum, 327  |
| See also friction, precision mechanics and; wear,  | ferrous density, 405–406, 406 (figure), 412   |
| precision mechanics and  | field testing, 215. See also bench tests; engine tests  |
| requirements, 112–113. See also bench tests; perfor-                                     | fill-for-life fluids, 273, 289, 317   |
| mance standards  | film thickness, 106 (figure), 132 (figure), 133 (figure), 216   |
| stability and, 51  | (figure), 353 (figure)  |
| tribological, 368  | additives and, 369  |
| valves and, 344  | elastohydrodynamic solutions and, 13, 14–15,  |
| wear and, 73, 76, 78   | 15 (figure), 85–87, 87 (figure)   |
| See also bearing tests; bearing vibration tests; bench                                   | measurement, 18, 200 (table)  |
| tests; elasohydrodynamics lubrication film (EHL)   | oil and, 321–323, 322 (figure)  |
| tests; engine material; laboratory tests; performance                                    | film-forming behavior, 320 (table), 321, 321–323. See also  |
| standards; tribological bench tests; <i>specific tests</i>                               | film thickness  |
| engineering surface, 3–9<br>environmental effect, 110, 209–210, 285, 317, 320–321        | filterability, 56–57, 79–80, 193 (table), 435   |
|  | filters, 427–429, 428 (figure)  |
| environmental scanning electron microscope (ESEM), 354                                   | capacity, 435   |
| environmental standard, 61–62, 231   | performance qualifications and, 430–431, 434 test methods and, 431–433                                  |
| environmental stress stimulation test, 152   | See also fuel filter; oil filter  |
| enzymatic hydrolysis, 49   | final drive units, 166, 167 (figure)  |
| EOWTT, 80  | fine filtration, 428  |
| epilamization, 388   | five speed automatic transmission, 255  |
| equation of motion, 11–12  | fixed ball joint, 140   |
| EREBIO, 326–327, 327 (figure), 328 (figure)  | flammability, 55  |
| esters, 320, 321, 323, 386, 458 (figure)   | flash point, 55–56. <i>See also</i> flash point test  |
| estolides, 458, 459 (table)  | flash point test, 409–410, 409 (figure), 412, 414   |
| ESW M2C138-CJ, 266, 267 (table)  | flat plate clutch, 256–257, 257 (figure)  |
| ESW M2C33, 266, 267 (table)  | "flexible fuel," 228  |
| ethanol-biodiesel-diesel blend, 419  | florescence, 54   |
| ethanol-diesel blend, 419 (figure)   | flow characteristics, 16–17, 18, 248 (figure), 434, 435   |
| ethyl alcohol, 254   | fluid behavior, 87–88   |
| ethylene acrylic rubber (AEM-1), 194 (table)   | fluid cleanliness rating, 402   |
| Europe, 259, 417   | fluorocarbon rubber (FKM-1), 115 (figure), 194 (table)  |

| foam control, 207, 265. See also foaming   | G  |
|--|--|
| foaming, 53, 70, 80, 193 (table), 196 (table), 241 (table).                        | Ga ions, 356   |
| See also antifoam agents; foam control   | galvanic coating, 335  |
| focused ion beam (FIB) material sputtering technique, 356                          | gas chromatography (CGD), 53<br>gas discharge, 119, 120                          |
| force-displacement, 359 (figure), 360 (figure)                                     | gasoline, 417. See also fuel   |
| Ford, 266–267  | gasoline engine tests, 191-194. See also engine tests                            |
| Fourier transform infrared (FTIR) spectroscopy,                                    | Gatto, V. J., 201  |
| 360, 365–366, 366 (figure), 404–405, 412, 413                                      | Gaussian asperity-height distribution, 4, 5, 17                                  |
| (figure), 414  | Ge, 367  |
| four-square test rig, 279 (figure)   | gear box, 159, 160, 161–164, 161 (figure), 162 (figure),                         |
| four-stroke engine, 119, 251–252   | 163 (figure), 164 (figure), 165 (figure). See also gear                          |
| fractal contact, 9   | box tests; in-line gear box; synchromesh testing                                 |
| France, 319  | gear box tests, 287–288  |
| free-volume viscosity model, 10  | gear oil, 178, 181, 288 (figure)   |
| friction alternative oils and, 325–327   | gear oil screen tests, 177 (table), 178, 180–186<br>gear selection, 274 (figure) |
| precision mechanics and, 392–394, 393 (figure), 394                                | gears  |
| (figure), 395 (figure)   | lubricants and, 182, 183 (table), 288  |
| static, 395 (figure)   | mesh, 169  |
| torque and, 149  | miniature, 379; 167–168, 180 (figure)  |
| See also friction coefficient; friction loss; friction                             | test, 179 (table), 179–180, 180 (figure)   |
| modifier; friction tests   | transmission, 345–346; wheel, 38   |
| friction coefficient, 262, 352, 353 (figure), 383 (figure),                        | See also gear box; specific gears  |
| 421–422, 421 (figure), 422 (figure), 440   | gelation index, 50, 75 (table), 75–76, 192 (table)                               |
| friction force microscopy (FFM), 357   | General Motors, 266, 267   |
| friction loss, 172, 333, 351, 352 (figure)   | generated axial force (GAF), 437, 438, 450                                       |
| friction model, 448-440, 449 (figure), 452 (figure)                                | gerotor pump, 110 (figure)   |
| friction modifier (FM), 27–28, 28 (figure), 29 (figure),                           | GF-4, 192–194 (table)  |
| 31 (table), 48   | GL-1, 38   |
| additives and, 29, (figure), 224, 362 (figure), 369                                | GL-2, 38   |
| (figure), 371–372, 371 (figure), 372 (figure)                                      | GL-3, 38   |
| performance criteria, 262–263  | GL-4, 38   |
| friction tests, 96 (table), 96–97, 217–219, 219 (figure),                          | GL-5, 38, 69 (table). See also ILSAC GF-5  |
| 356 (figure), 369  | GL-6, 38–39<br>global elasticity, 18–19  |
| friction-sliding-elastic contact, 304<br>friction-temperature regime, 334 (figure) | glycol reagent method, 410   |
| front-wheel drive, 159 (figure)  | GM-9099P, 56   |
| FTMS Method No. 3458.1, 391  | government regulations, 227. See also environmental                              |
| F2G gear test rig, 100, 181, 182, 188  | standards  |
| Fuchs. See Titan GT1 0W-20   | gravimetric analysis, 430  |
| fuel   | grease, 40–45, 137, 138 (table), 142–143, 143 (figure),                          |
| alternative, 218, 228–229  | 387  |
| diesel, 68, 75, 120, 239-240, 417-423, 418 (figure),                               | auxiliary parts and, 14  |
| 432–433  | biobased, 464–466  |
| dilution of, 409, 410, 414   | constant velocity universal joints and, 140-142, 141                             |
| lubricity and, 417-418, 418 (figure). See also lubricity                           | (figure)   |
| tests  | electrical parts and, 142, 143   |
| quality of, 239–240. See also biodiesel  | hub bearings and, 137–139, 138 (table), 139 (figure)                             |
| hydrocarbons in, 105, 106, 226   | life of, 151–152   |
| See also additives; fuel economy; fuel efficiency;                                 | measurement technology and, 144–146, 145 (figure)                                |
| specific types   | 146 (table)<br>requirements, 137–138   |
| fuel consumption, 61, 77, 123 (figure). See also oil consumption                   | Green's functions, 5   |
| fuel economy, 227–228, 317, 351  | Greentec LS 5W-30, 320 (table), 321, 323 (table), 324                            |
| fuel efficiency, 77, 78, 105, 110–111, 113, 192 (table), 202                       | Greentee Lo 3 W-30, 320 (table), 321, 323 (table), 324                           |
| fuel filter, 431–433   | Н  |
| fuel injector, 418 (figure), 422–423, 422 (table)                                  | haptic demands, 385  |
| full-flow oil, 428–429   | hardness, 358–359  |
| full-scale mixed EHL model, 89, 90   | heat capacity, 108. See also temperature   |
| FZG back-to-back rig, 178–179, 179 (figure), 181                                   | heavy-duty diesel, 82, 159, 232  |
| FZG-type test rig, 279 (figure)  | API and, 240–241   |

AST-MNL62-12-0501-IND.indd 487 01/10/12 6:57 PM

| lubricants for, 233–234, 237   | injection timing, 237   |
|--|---|
| See also diesel engine   | inlet antidrain, 435  |
| heavy-duty trailer-towing, 278   | in-line gear box, 13 (figure), 163–164                        |
| helical gears, 167, 168  | inorganic contamination, 429                                  |
| Herrebrugh's solution, 15  | intake, 105 interactive deterministic-stochastic modeling, 15 |
| Hersey number, 13  | internal combustion engine, 105–106, 106 (figure),            |
| Hertz theory of elastic contact, 7, 302                                  | 119–120   |
| Hertzian formulas, 7, 8, 9, 19<br>HFRR, 420                              | ILSAC GF-5 and, 110–115                                       |
| high-frequency reciprocating rig (HFRR), 204                             | lubrication requirements of, 106–110, 107 (figure), 109       |
| high-shear viscometer, 323   | (figure), 110 (figure)  |
| high shear viscosity, 50, 68–70, 196 (table), 319, 321–323               | mechanisms of wear, 110                                       |
| high-temperature corrosion bench test, 196 (table), 241                  | pollutant emissions and, 126–127                              |
| (table)  | powertrain and, 124–126                                       |
| high-temperature deposit, 57   | See also combustion engine architecture; engine; en-          |
| high-temperature test life, 1369   | gine tests; gasoline engine tests; specific components        |
| high-temperature viscosity, 50   | specific tests  |
| high-temperature, high-shear (HTHS) viscosity, 50,                       | International Council of Marine Industry Associations         |
| 68–70, 196 (table), 319, 321–323   | (INCOMIA), 253  |
| Hooke's joints, 42   | International Lubricants Standardization and Approval         |
| hot-scuffing, 225  | Committee (ILSAC), 64, 65, 217, 226, 244. See also            |
| HTHS stability, 69 (table)   | specific specifications                                       |
| HTX 822 15W-50, 320 (table), 321, 323, 324, 325                          | involute curve, 168 (figure)                                  |
| Hu, Y. Z., 89, 90  | IP Method, 56   |
| hub bearing, 137-139, 138 (table), 139 (figure), 149. See                | iron liners, 372  |
| also hub bearing tests   | ISO 12103-1, 430  |
| hub bearing tests, 149. See also ABFT                                    | ISO 19438, 432–433  |
| hybrid thickeners, 41  | ISO 4020, 432   |
| hybrid vehicles, 160, 254  | ISO 4406:99, 402 (figure)                                     |
| hydraulic pulse durability, 435  | ISO 4548, 434–435   |
| hydrocarbon (HC), 27-28, 126, 262  | ISO/TS 16332, 433   |
| hydrodynamic lubrication, 11, 12, 15-19                                  | ISO/TS, 13353, 432  |
| hydrogenated nitrile rubber (HNBR-1), 115 (table), 194                   | ISO/TS 23556, 436   |
| (table)  | ISO 7148-2, 392   |
| hydrogenated radial isoprenes (RIs), 25                                  | isothermal contact simulations, 8                             |
| hydrogenated styrene butadiene copolymers (SBCs), 24                     | isotropic, 5 (figure)   |
| (figure), 25   |   |
| hydrogenated styrene isoprene copolymers (SICs), 24                      | J   |
| (figure), 25   | Japan, 67   |
| hydrolic valve lifters, 109  | JASO, 246–247, 250 (table), 251–252, 253                      |
| hydroxide, 263   | Johnson et al., 90–91, 91 (figure), 91 (table)                |
|  | journal bearings, 18, 19, 129–132, 130 (figure), 131          |
| TOOT! (1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1                             | (figure), 341. See also bearings                              |
| ICOT (isothermal corrosion oxidation test), 219, 323–                    | V   |
| 324, 325 (figure)  | K  Wante at al. 01. 02. 02 (Farms) 02 (table) 02 (Farms) 04   |
| ignition timing, 231 ILSAC. See International Lubricants Standardization | Kaneta et al, 91–93, 92 (figure), 92 (table), 93 (figure), 94 |
| and Approval Committee (ILSAC) ILSAC GF-4, 227                           | (figure)<br>Karl Fischer Titration, 408, 430, 431 (figure)    |
| ILSAC GF-5, 49, 64, 65, 74–82, 110–111, 227                              | Kégresse, Adolhpe, 37   |
| requirements, 112–114, 115 (table), 244–245, 248–249                     | kinematic viscosity, 49                                       |
| (table)  | kinematics, 121–122   |
| test methods, 192–194 (table)  | kurtosis, 4, 5  |
| viscosity and, 246 (table)   | Kartoolo, 1, 5  |
| See also API GF-5  | L   |
| indirect laser transmission method, 86                                   | laboratory tests, 62, 218                                     |
| inductively coupled plasma (ICP) spectrometer, 408                       | ACEA and, 232–237, 234 (figure), 235 (table)                  |
| industrial applications, 180 (figure), 180–181                           | API and, 238–244  |
| industrial crops, 456  | heavy duty diesel lubricants and, 70–72                       |
| infinite life, 275   | ILSAC and, 245  |
| infrared spectroscopy, 405 (figure)                                      | performance standards and, 61, 62-63, 62 (figure), 233        |
| injection molding skin, 396  | (table)   |
| injection system, 417  | screening test, 64  |

AST-MNL62-12-0501-IND.indd 488 01/10/12 6:57 PM

| wear and, 307-308, 308 (figure), 309   | metal oxide, l263  |
|--|--|
| See also bench tests; engine tests; specific performance   | metal passivators, 48  |
| standards; specific tests  | metal salts or organic acids (soaps), 263, 264 (figure)  |
| laser transmission method, 86  | methanol, 228  |
| lateral force microscopy (LFM), 357  | MHT-4, 79  |
| layered materials, 3, 9  | microgeometry, 217 (table)   |
| layshaft, 169  | micropitting test, 183–185, 184 (figure), 185 (figure)   |
| lead, 407  | microscopic contaminant, 406–407   |
| lean mixtures, 126–127   | microtribosystem, 293–294, 295 (figure)  |
| leptokurtic, 5   | mineral oil, 11, 35, 183 (figure), 187, 259–260, 260   |
| life tester, 147, 149  | (table)  |
| light vehicle. See passenger cars  | miniature gears, 379   |
| Lim and Ashby wear map, 304, 305 (figure)  | mini-rotary viscometer (MRV), 50, 51   |
| line contact, 5, 6 (figure), 303 (figure)  | Mini-Traction Machine (MTM®), 204–205  |
| linear curve-fit, 443 (figure)   | miscibility, 57, 81  |
| linear wear coefficient C <sub>lt</sub> , 183 (figure)   | mixed lubrication, 12-13, 19, 301. See also biofuel  |
| lithium, 142   | modeling, 15, 304–305  |
| lithium hydroxide soap-based grease, 465   | constant velocity joints (CVJ) and, 446–452, 452 (figure)  |
| load carrying, 14, 178, 179, 181–188, 181 (table), 186   | wear and, 294, 304-305, 305 (table), 310-311, 314  |
| (figure), 341  | MoDTC. See molybdenum dithiocarbamate (MoDTC)  |
| load loss factor, 188 (figure)   | moisture contamination, 412–413  |
| low temperature, 20, 261 (figure), 391. See also temperature   | molybdenum dithiocarbamate (MoDTC), 29, (figure),  |
| low-sulfur fuel, 417, 418. See also alternative fluid  | 224, 362 (figure), 369 (figure), 371–372, 371 (figure),  |
| lubricant, 40–41, 217 (table)  | 372 (figure), 374  |
| components of, 47–48   | molybdenum oxide, 327  |
| degradation and, 61-63, 66-67. See also degradation  | motor, 380–381, 380 (figure)   |
| gear, 182, 183 (table)   | motorcycle engine lubrication, 251–252, 253  |
| physical properties of, 45–57  | movable glass plate, 86  |
| in precision mechanics, 384–391, 387 (figure), 388   | MS-4228, 266   |
| (figure)   | multicylinder configurations, 124, 125   |
| requirements, 106–110  | multiple test acceptance cirteria (MTAC), 64   |
|  |  |
| solid, 387   |  |
| solid, 387  See also additive; axle fluid, grease; engine oil; grease;   | N  |
|  | N<br>nanoindenter, 358–360   |
| See also additive; axle fluid, grease; engine oil; grease;   |  |
| See also additive; axle fluid, grease; engine oil; grease; specific performance standards; specific properties;  | nanoindenter, 358-360  |
| See also additive; axle fluid, grease; engine oil; grease; specific performance standards; specific properties; specific test methods; transmission fluid  | nanoindenter, 358–360<br>naphthenic oil, 41, 261   |
| See also additive; axle fluid, grease; engine oil; grease; specific performance standards; specific properties; specific test methods; transmission fluid lubricating grease life test rig, 151 (figure)   | nanoindenter, 358–360<br>naphthenic oil, 41, 261<br>Natural Marine Manufacturing Association (NMMA),   |
| See also additive; axle fluid, grease; engine oil; grease; specific performance standards; specific properties; specific test methods; transmission fluid lubricating grease life test rig, 151 (figure) lubricious oxides (LOs), 319  | nanoindenter, 358–360<br>naphthenic oil, 41, 261<br>Natural Marine Manufacturing Association (NMMA),<br>252, 253 (table)   |
| See also additive; axle fluid, grease; engine oil; grease; specific performance standards; specific properties; specific test methods; transmission fluid lubricating grease life test rig, 151 (figure) lubricious oxides (LOs), 319 lubricity tests, 420 (figure). See also bench tests; engine  | nanoindenter, 358–360<br>naphthenic oil, 41, 261<br>Natural Marine Manufacturing Association (NMMA),<br>252, 253 (table)<br>neutral detergent, 33, 34 (table), 47. <i>See also</i> detergent   |
| See also additive; axle fluid, grease; engine oil; grease; specific performance standards; specific properties; specific test methods; transmission fluid lubricating grease life test rig, 151 (figure) lubricious oxides (LOs), 319 lubricity tests, 420 (figure). See also bench tests; engine tests; laboratory tests; specific tests  | nanoindenter, 358–360<br>naphthenic oil, 41, 261<br>Natural Marine Manufacturing Association (NMMA),<br>252, 253 (table)<br>neutral detergent, 33, 34 (table), 47. <i>See also</i> detergent<br>Newton ideology, 49, 202<br>nitriding, 334–335, 343  |
| See also additive; axle fluid, grease; engine oil; grease; specific performance standards; specific properties; specific test methods; transmission fluid lubricating grease life test rig, 151 (figure) lubricious oxides (LOs), 319 lubricity tests, 420 (figure). See also bench tests; engine tests; laboratory tests; specific tests Lubrizol Corporation, 455  | nanoindenter, 358–360<br>naphthenic oil, 41, 261<br>Natural Marine Manufacturing Association (NMMA),<br>252, 253 (table)<br>neutral detergent, 33, 34 (table), 47. <i>See also</i> detergent<br>Newton ideology, 49, 202   |
| See also additive; axle fluid, grease; engine oil; grease; specific performance standards; specific properties; specific test methods; transmission fluid lubricating grease life test rig, 151 (figure) lubricious oxides (LOs), 319 lubricity tests, 420 (figure). See also bench tests; engine tests; laboratory tests; specific tests Lubrizol Corporation, 455 Luk continuously variable transmission chain, 259  | nanoindenter, 358–360 naphthenic oil, 41, 261 Natural Marine Manufacturing Association (NMMA), 252, 253 (table) neutral detergent, 33, 34 (table), 47. See also detergent Newton ideology, 49, 202 nitriding, 334–335, 343 nitrocarburizing, 335   |
| See also additive; axle fluid, grease; engine oil; grease; specific performance standards; specific properties; specific test methods; transmission fluid lubricating grease life test rig, 151 (figure) lubricious oxides (LOs), 319 lubricity tests, 420 (figure). See also bench tests; engine tests; laboratory tests; specific tests Lubrizol Corporation, 455 Luk continuously variable transmission chain, 259  | nanoindenter, 358–360 naphthenic oil, 41, 261 Natural Marine Manufacturing Association (NMMA), 252, 253 (table) neutral detergent, 33, 34 (table), 47. See also detergent Newton ideology, 49, 202 nitriding, 334–335, 343 nitrocarburizing, 335 nitrogen oxides (NOs), 126, 231   |
| See also additive; axle fluid, grease; engine oil; grease; specific performance standards; specific properties; specific test methods; transmission fluid lubricating grease life test rig, 151 (figure) lubricious oxides (LOs), 319 lubricity tests, 420 (figure). See also bench tests; engine tests; laboratory tests; specific tests Lubrizol Corporation, 455 Luk continuously variable transmission chain, 259 (figure)   | nanoindenter, 358–360 naphthenic oil, 41, 261 Natural Marine Manufacturing Association (NMMA), 252, 253 (table) neutral detergent, 33, 34 (table), 47. See also detergent Newton ideology, 49, 202 nitriding, 334–335, 343 nitrocarburizing, 335 nitrogen oxides (NOs), 126, 231 NLGI certification marks, 45  |
| See also additive; axle fluid, grease; engine oil; grease; specific performance standards; specific properties; specific test methods; transmission fluid lubricating grease life test rig, 151 (figure) lubricious oxides (LOs), 319 lubricity tests, 420 (figure). See also bench tests; engine tests; laboratory tests; specific tests Lubrizol Corporation, 455 Luk continuously variable transmission chain, 259 (figure)   | nanoindenter, 358–360 naphthenic oil, 41, 261 Natural Marine Manufacturing Association (NMMA), 252, 253 (table) neutral detergent, 33, 34 (table), 47. See also detergent Newton ideology, 49, 202 nitriding, 334–335, 343 nitrocarburizing, 335 nitrogen oxides (NOs), 126, 231 NLGI certification marks, 45 NOACK Volatility Test, 71 (table), 196 (table), 241 (table)  |
| See also additive; axle fluid, grease; engine oil; grease; specific performance standards; specific properties; specific test methods; transmission fluid lubricating grease life test rig, 151 (figure) lubricious oxides (LOs), 319 lubricity tests, 420 (figure). See also bench tests; engine tests; laboratory tests; specific tests Lubrizol Corporation, 455 Luk continuously variable transmission chain, 259 (figure)  M M2C166-H, 266, 267 (table)   | nanoindenter, 358–360 naphthenic oil, 41, 261 Natural Marine Manufacturing Association (NMMA), 252, 253 (table) neutral detergent, 33, 34 (table), 47. See also detergent Newton ideology, 49, 202 nitriding, 334–335, 343 nitrocarburizing, 335 nitrogen oxides (NOs), 126, 231 NLGI certification marks, 45 NOACK Volatility Test, 71 (table), 196 (table), 241 (table) noise suppression, 385   |
| See also additive; axle fluid, grease; engine oil; grease; specific performance standards; specific properties; specific test methods; transmission fluid lubricating grease life test rig, 151 (figure) lubricious oxides (LOs), 319 lubricity tests, 420 (figure). See also bench tests; engine tests; laboratory tests; specific tests Lubrizol Corporation, 455 Luk continuously variable transmission chain, 259 (figure)  M  M2C166-H, 266, 267 (table) M85, 228   | nanoindenter, 358–360 naphthenic oil, 41, 261 Natural Marine Manufacturing Association (NMMA), 252, 253 (table) neutral detergent, 33, 34 (table), 47. See also detergent Newton ideology, 49, 202 nitriding, 334–335, 343 nitrocarburizing, 335 nitrogen oxides (NOs), 126, 231 NLGI certification marks, 45 NOACK Volatility Test, 71 (table), 196 (table), 241 (table) noise suppression, 385 non-automotive engine, 252–253  |
| See also additive; axle fluid, grease; engine oil; grease; specific performance standards; specific properties; specific test methods; transmission fluid lubricating grease life test rig, 151 (figure) lubricious oxides (LOs), 319 lubricity tests, 420 (figure). See also bench tests; engine tests; laboratory tests; specific tests Lubrizol Corporation, 455 Luk continuously variable transmission chain, 259 (figure)  M M2C166-H, 266, 267 (table) M85, 228 Mack T-11, 73, 195 (table), 197, 199 (table), 242 (table)  | nanoindenter, 358–360 naphthenic oil, 41, 261 Natural Marine Manufacturing Association (NMMA), 252, 253 (table) neutral detergent, 33, 34 (table), 47. See also detergent Newton ideology, 49, 202 nitriding, 334–335, 343 nitrocarburizing, 335 nitrogen oxides (NOs), 126, 231 NLGI certification marks, 45 NOACK Volatility Test, 71 (table), 196 (table), 241 (table) noise suppression, 385 non-automotive engine, 252–253 nonbridgine oxygen (NBO), 370  |
| See also additive; axle fluid, grease; engine oil; grease; specific performance standards; specific properties; specific test methods; transmission fluid lubricating grease life test rig, 151 (figure) lubricious oxides (LOs), 319 lubricity tests, 420 (figure). See also bench tests; engine tests; laboratory tests; specific tests Lubrizol Corporation, 455 Luk continuously variable transmission chain, 259 (figure)  M  M2C166-H, 266, 267 (table) M85, 228 Mack T-11, 73, 195 (table), 197, 199 (table), 242 (table) Mack T-12, 73 (table), 197, 199 (table), 242 (table)  | nanoindenter, 358–360 naphthenic oil, 41, 261 Natural Marine Manufacturing Association (NMMA), 252, 253 (table) neutral detergent, 33, 34 (table), 47. See also detergent Newton ideology, 49, 202 nitriding, 334–335, 343 nitrocarburizing, 335 nitrogen oxides (NOs), 126, 231 NLGI certification marks, 45 NOACK Volatility Test, 71 (table), 196 (table), 241 (table) noise suppression, 385 non-automotive engine, 252–253 nonbridgine oxygen (NBO), 370 nonconformal contact, 5  |
| See also additive; axle fluid, grease; engine oil; grease; specific performance standards; specific properties; specific test methods; transmission fluid lubricating grease life test rig, 151 (figure) lubricious oxides (LOs), 319 lubricity tests, 420 (figure). See also bench tests; engine tests; laboratory tests; specific tests Lubrizol Corporation, 455 Luk continuously variable transmission chain, 259 (figure)  M M2C166-H, 266, 267 (table) M85, 228 Mack T-11, 73, 195 (table), 197, 199 (table), 242 (table) Mack T-12, 73 (table), 197, 199 (table), 242 (table) macrogeometry, 217 (table)  | nanoindenter, 358–360 naphthenic oil, 41, 261 Natural Marine Manufacturing Association (NMMA), 252, 253 (table) neutral detergent, 33, 34 (table), 47. See also detergent Newton ideology, 49, 202 nitriding, 334–335, 343 nitrocarburizing, 335 nitrogen oxides (NOs), 126, 231 NLGI certification marks, 45 NOACK Volatility Test, 71 (table), 196 (table), 241 (table) noise suppression, 385 non-automotive engine, 252–253 nonbridgine oxygen (NBO), 370 nonconformal contact, 5 non-soap thickened grease, 41  |
| See also additive; axle fluid, grease; engine oil; grease; specific performance standards; specific properties; specific test methods; transmission fluid lubricating grease life test rig, 151 (figure) lubricious oxides (LOs), 319 lubricity tests, 420 (figure). See also bench tests; engine tests; laboratory tests; specific tests Lubrizol Corporation, 455 Luk continuously variable transmission chain, 259 (figure)  M  M2C166-H, 266, 267 (table) M85, 228  Mack T-11, 73, 195 (table), 197, 199 (table), 242 (table) Mack T-12, 73 (table), 197, 199 (table), 242 (table) macrogeometry, 217 (table) macrotribosystem, 293–294, 295 (figure)  | nanoindenter, 358–360 naphthenic oil, 41, 261 Natural Marine Manufacturing Association (NMMA), 252, 253 (table) neutral detergent, 33, 34 (table), 47. See also detergent Newton ideology, 49, 202 nitriding, 334–335, 343 nitrocarburizing, 335 nitrogen oxides (NOs), 126, 231 NLGI certification marks, 45 NOACK Volatility Test, 71 (table), 196 (table), 241 (table) noise suppression, 385 non-automotive engine, 252–253 nonbridgine oxygen (NBO), 370 nonconformal contact, 5 non-soap thickened grease, 41 nonsoap-based grease, 465  |
| See also additive; axle fluid, grease; engine oil; grease; specific performance standards; specific properties; specific test methods; transmission fluid lubricating grease life test rig, 151 (figure) lubricious oxides (LOs), 319 lubricity tests, 420 (figure). See also bench tests; engine tests; laboratory tests; specific tests Lubrizol Corporation, 455 Luk continuously variable transmission chain, 259 (figure)  M  M2C166-H, 266, 267 (table) M85, 228  Mack T-11, 73, 195 (table), 197, 199 (table), 242 (table) Mack T-12, 73 (table), 197, 199 (table), 242 (table) macrogeometry, 217 (table) macrotribosystem, 293–294, 295 (figure) manual transmission (MT), 267, 279–282. See also dual-   | nanoindenter, 358–360 naphthenic oil, 41, 261 Natural Marine Manufacturing Association (NMMA), 252, 253 (table) neutral detergent, 33, 34 (table), 47. See also detergent Newton ideology, 49, 202 nitriding, 334–335, 343 nitrocarburizing, 335 nitrogen oxides (NOs), 126, 231 NLGI certification marks, 45 NOACK Volatility Test, 71 (table), 196 (table), 241 (table) noise suppression, 385 non-automotive engine, 252–253 nonbridgine oxygen (NBO), 370 nonconformal contact, 5 non-soap thickened grease, 41 nonsoap-based grease, 465 nonvacuum-based technique, 365–366   |
| See also additive; axle fluid, grease; engine oil; grease; specific performance standards; specific properties; specific test methods; transmission fluid lubricating grease life test rig, 151 (figure) lubricious oxides (LOs), 319 lubricity tests, 420 (figure). See also bench tests; engine tests; laboratory tests; specific tests Lubrizol Corporation, 455 Luk continuously variable transmission chain, 259 (figure)  M  M2C166-H, 266, 267 (table) M85, 228  Mack T-11, 73, 195 (table), 197, 199 (table), 242 (table) Mack T-12, 73 (table), 197, 199 (table), 242 (table) macrogeometry, 217 (table) macrotribosystem, 293–294, 295 (figure) manual transmission (MT), 267, 279–282. See also dual-clutch transmission (DTC); gear box; synchromesh; synchromesh testing materials. See engine materials  | nanoindenter, 358–360 naphthenic oil, 41, 261 Natural Marine Manufacturing Association (NMMA), 252, 253 (table) neutral detergent, 33, 34 (table), 47. See also detergent Newton ideology, 49, 202 nitriding, 334–335, 343 nitrocarburizing, 335 nitrogen oxides (NOs), 126, 231 NLGI certification marks, 45 NOACK Volatility Test, 71 (table), 196 (table), 241 (table) noise suppression, 385 non-automotive engine, 252–253 nonbridgine oxygen (NBO), 370 nonconformal contact, 5 non-soap thickened grease, 41 nonsoap-based grease, 465 nonvacuum-based technique, 365–366 normal fatigue loading, 275 North American performance standards, 64. See also American Performance Institiute (API); American So-  |
| See also additive; axle fluid, grease; engine oil; grease; specific performance standards; specific properties; specific test methods; transmission fluid lubricating grease life test rig, 151 (figure) lubricious oxides (LOs), 319 lubricity tests, 420 (figure). See also bench tests; engine tests; laboratory tests; specific tests Lubrizol Corporation, 455 Luk continuously variable transmission chain, 259 (figure)  M  M2C166-H, 266, 267 (table) M85, 228  Mack T-11, 73, 195 (table), 197, 199 (table), 242 (table) Mack T-12, 73 (table), 197, 199 (table), 242 (table) macrogeometry, 217 (table) macrotribosystem, 293–294, 295 (figure) manual transmission (MT), 267, 279–282. See also dual-clutch transmission (DTC); gear box; synchromesh; synchromesh testing  | nanoindenter, 358–360 naphthenic oil, 41, 261 Natural Marine Manufacturing Association (NMMA), 252, 253 (table) neutral detergent, 33, 34 (table), 47. See also detergent Newton ideology, 49, 202 nitriding, 334–335, 343 nitrocarburizing, 335 nitrogen oxides (NOs), 126, 231 NLGI certification marks, 45 NOACK Volatility Test, 71 (table), 196 (table), 241 (table) noise suppression, 385 non-automotive engine, 252–253 nonbridgine oxygen (NBO), 370 nonconformal contact, 5 non-soap thickened grease, 41 nonsoap-based grease, 465 nonvacuum-based technique, 365–366 normal fatigue loading, 275 North American performance standards, 64. See also  |
| See also additive; axle fluid, grease; engine oil; grease; specific performance standards; specific properties; specific test methods; transmission fluid lubricating grease life test rig, 151 (figure) lubricious oxides (LOs), 319 lubricity tests, 420 (figure). See also bench tests; engine tests; laboratory tests; specific tests Lubrizol Corporation, 455 Luk continuously variable transmission chain, 259 (figure)  M  M2C166-H, 266, 267 (table) M85, 228  Mack T-11, 73, 195 (table), 197, 199 (table), 242 (table) Mack T-12, 73 (table), 197, 199 (table), 242 (table) macrogeometry, 217 (table) macrogeometry, 217 (table) macrotribosystem, 293–294, 295 (figure) manual transmission (MT), 267, 279–282. See also dual-clutch transmission (DTC); gear box; synchromesh; synchromesh testing materials. See engine materials manual transmission fluid (MTF), 37, 289 maximum specific load (MSL), 129   | nanoindenter, 358–360 naphthenic oil, 41, 261 Natural Marine Manufacturing Association (NMMA), 252, 253 (table) neutral detergent, 33, 34 (table), 47. See also detergent Newton ideology, 49, 202 nitriding, 334–335, 343 nitrocarburizing, 335 nitrogen oxides (NOs), 126, 231 NLGI certification marks, 45 NOACK Volatility Test, 71 (table), 196 (table), 241 (table) noise suppression, 385 non-automotive engine, 252–253 nonbridgine oxygen (NBO), 370 nonconformal contact, 5 non-soap thickened grease, 41 nonsoap-based grease, 465 nonvacuum-based technique, 365–366 normal fatigue loading, 275 North American performance standards, 64. See also American Performance Institiute (API); American Society for Testing and Materials (ASTM); API Tripartite system; specific performance standards  |
| See also additive; axle fluid, grease; engine oil; grease; specific performance standards; specific properties; specific test methods; transmission fluid lubricating grease life test rig, 151 (figure) lubricious oxides (LOs), 319 lubricity tests, 420 (figure). See also bench tests; engine tests; laboratory tests; specific tests Lubrizol Corporation, 455 Luk continuously variable transmission chain, 259 (figure)  M  M2C166-H, 266, 267 (table) M85, 228  Mack T-11, 73, 195 (table), 197, 199 (table), 242 (table) Mack T-12, 73 (table), 197, 199 (table), 242 (table) macrogeometry, 217 (table) macrogeometry, 217 (table) macrotribosystem, 293–294, 295 (figure) manual transmission (MT), 267, 279–282. See also dual-clutch transmission (DTC); gear box; synchromesh; synchromesh testing materials. See engine materials manual transmission fluid (MTF), 37, 289 maximum specific load (MSL), 129 Maxwell model, 10   | nanoindenter, 358–360 naphthenic oil, 41, 261 Natural Marine Manufacturing Association (NMMA), 252, 253 (table) neutral detergent, 33, 34 (table), 47. See also detergent Newton ideology, 49, 202 nitriding, 334–335, 343 nitrocarburizing, 335 nitrogen oxides (NOs), 126, 231 NLGI certification marks, 45 NOACK Volatility Test, 71 (table), 196 (table), 241 (table) noise suppression, 385 non-automotive engine, 252–253 nonbridgine oxygen (NBO), 370 nonconformal contact, 5 non-soap thickened grease, 41 nonsoap-based grease, 465 nonvacuum-based technique, 365–366 normal fatigue loading, 275 North American performance standards, 64. See also American Performance Institiute (API); American Society for Testing and Materials (ASTM); API Tripartite system; specific performance standards Novack volatility method, 53                           |
| See also additive; axle fluid, grease; engine oil; grease; specific performance standards; specific properties; specific test methods; transmission fluid lubricating grease life test rig, 151 (figure) lubricious oxides (LOs), 319 lubricity tests, 420 (figure). See also bench tests; engine tests; laboratory tests; specific tests Lubrizol Corporation, 455 Luk continuously variable transmission chain, 259 (figure)  M  M2C166-H, 266, 267 (table) M85, 228  Mack T-11, 73, 195 (table), 197, 199 (table), 242 (table) Mack T-12, 73 (table), 197, 199 (table), 242 (table) macrogeometry, 217 (table) macrogeometry, 217 (table) macrotribosystem, 293–294, 295 (figure) manual transmission (MT), 267, 279–282. See also dual-clutch transmission (DTC); gear box; synchromesh; synchromesh testing materials. See engine materials manual transmission fluid (MTF), 37, 289 maximum specific load (MSL), 129   | nanoindenter, 358–360 naphthenic oil, 41, 261 Natural Marine Manufacturing Association (NMMA), 252, 253 (table) neutral detergent, 33, 34 (table), 47. See also detergent Newton ideology, 49, 202 nitriding, 334–335, 343 nitrocarburizing, 335 nitrogen oxides (NOs), 126, 231 NLGI certification marks, 45 NOACK Volatility Test, 71 (table), 196 (table), 241 (table) noise suppression, 385 non-automotive engine, 252–253 nonbridgine oxygen (NBO), 370 nonconformal contact, 5 non-soap thickened grease, 41 nonsoap-based grease, 465 nonvacuum-based technique, 365–366 normal fatigue loading, 275 North American performance standards, 64. See also American Performance Institiute (API); American Society for Testing and Materials (ASTM); API Tripartite system; specific performance standards  |
| See also additive; axle fluid, grease; engine oil; grease; specific performance standards; specific properties; specific test methods; transmission fluid lubricating grease life test rig, 151 (figure) lubricious oxides (LOs), 319 lubricity tests, 420 (figure). See also bench tests; engine tests; laboratory tests; specific tests  Lubrizol Corporation, 455  Luk continuously variable transmission chain, 259 (figure)  M  M2C166-H, 266, 267 (table)  M85, 228  Mack T-11, 73, 195 (table), 197, 199 (table), 242 (table)  Mack T-12, 73 (table), 197, 199 (table), 242 (table)  macrogeometry, 217 (table)  macrotribosystem, 293–294, 295 (figure)  manual transmission (MT), 267, 279–282. See also dual-clutch transmission (DTC); gear box; synchromesh; synchromesh testing  materials. See engine materials  manual transmission fluid (MTF), 37, 289  maximum specific load (MSL), 129  Maxwell model, 10  medium-temperature dispersivity, 78  melt wear, 383 (figure), 384 (figure)   | nanoindenter, 358–360 naphthenic oil, 41, 261 Natural Marine Manufacturing Association (NMMA), 252, 253 (table) neutral detergent, 33, 34 (table), 47. See also detergent Newton ideology, 49, 202 nitriding, 334–335, 343 nitrocarburizing, 335 nitrogen oxides (NOs), 126, 231 NLGI certification marks, 45 NOACK Volatility Test, 71 (table), 196 (table), 241 (table) noise suppression, 385 non-automotive engine, 252–253 nonbridgine oxygen (NBO), 370 nonconformal contact, 5 non-soap thickened grease, 41 nonsoap-based grease, 465 nonvacuum-based technique, 365–366 normal fatigue loading, 275 North American performance standards, 64. See also American Performance Institiute (API); American Society for Testing and Materials (ASTM); API Tripartite system; specific performance standards Novack volatility method, 53                           |
| See also additive; axle fluid, grease; engine oil; grease; specific performance standards; specific properties; specific test methods; transmission fluid lubricating grease life test rig, 151 (figure) lubricious oxides (LOs), 319 lubricity tests, 420 (figure). See also bench tests; engine tests; laboratory tests; specific tests Lubrizol Corporation, 455 Luk continuously variable transmission chain, 259 (figure)  M  M2C166-H, 266, 267 (table) M85, 228  Mack T-11, 73, 195 (table), 197, 199 (table), 242 (table) Mack T-12, 73 (table), 197, 199 (table), 242 (table) macrogeometry, 217 (table) macrogeometry, 217 (table) macrotribosystem, 293–294, 295 (figure) manual transmission (MT), 267, 279–282. See also dual-clutch transmission (DTC); gear box; synchromesh; synchromesh testing materials. See engine materials manual transmission fluid (MTF), 37, 289 maximum specific load (MSL), 129 Maxwell model, 10 medium-temperature dispersivity, 78 melt wear, 383 (figure), 384 (figure) MERCON®, 266–267, 267 (table) | nanoindenter, 358–360 naphthenic oil, 41, 261 Natural Marine Manufacturing Association (NMMA), 252, 253 (table) neutral detergent, 33, 34 (table), 47. See also detergent Newton ideology, 49, 202 nitriding, 334–335, 343 nitrocarburizing, 335 nitrogen oxides (NOs), 126, 231 NLGI certification marks, 45 NOACK Volatility Test, 71 (table), 196 (table), 241 (table) noise suppression, 385 non-automotive engine, 252–253 nonbridgine oxygen (NBO), 370 nonconformal contact, 5 non-soap thickened grease, 41 nonsoap-based grease, 465 nonvacuum-based technique, 365–366 normal fatigue loading, 275 North American performance standards, 64. See also American Performance Institiute (API); American Society for Testing and Materials (ASTM); API Tripartite system; specific performance standards Novack volatility method, 53 numerical surface, 3–4, 8 |
| See also additive; axle fluid, grease; engine oil; grease; specific performance standards; specific properties; specific test methods; transmission fluid lubricating grease life test rig, 151 (figure) lubricious oxides (LOs), 319 lubricity tests, 420 (figure). See also bench tests; engine tests; laboratory tests; specific tests  Lubrizol Corporation, 455  Luk continuously variable transmission chain, 259 (figure)  M  M2C166-H, 266, 267 (table)  M85, 228  Mack T-11, 73, 195 (table), 197, 199 (table), 242 (table)  Mack T-12, 73 (table), 197, 199 (table), 242 (table)  macrogeometry, 217 (table)  macrotribosystem, 293–294, 295 (figure)  manual transmission (MT), 267, 279–282. See also dual-clutch transmission (DTC); gear box; synchromesh; synchromesh testing  materials. See engine materials  manual transmission fluid (MTF), 37, 289  maximum specific load (MSL), 129  Maxwell model, 10  medium-temperature dispersivity, 78  melt wear, 383 (figure), 384 (figure)   | nanoindenter, 358–360 naphthenic oil, 41, 261 Natural Marine Manufacturing Association (NMMA), 252, 253 (table) neutral detergent, 33, 34 (table), 47. See also detergent Newton ideology, 49, 202 nitriding, 334–335, 343 nitrocarburizing, 335 nitrogen oxides (NOs), 126, 231 NLGI certification marks, 45 NOACK Volatility Test, 71 (table), 196 (table), 241 (table) noise suppression, 385 non-automotive engine, 252–253 nonbridgine oxygen (NBO), 370 nonconformal contact, 5 non-soap thickened grease, 41 nonsoap-based grease, 465 nonvacuum-based technique, 365–366 normal fatigue loading, 275 North American performance standards, 64. See also American Performance Institiute (API); American Society for Testing and Materials (ASTM); API Tripartite system; specific performance standards Novack volatility method, 53 numerical surface, 3–4, 8 |

AST-MNL62-12-0501-IND.indd 489 01/10/12 6:57 PM

| oil  | passenger cars   |
|--|--|
| protection additives, 23, 26–27, 41                            | drain intervals, 371                                       |
| robustness, 111  | engine tests, 74–76, 243–244, 245 (table)                  |
| sampling methods, 399–401, 400 (figure), 462                   | fuel and, 333, 432   |
| stability, 427–428   | grease and, 41-43  |
| supply, 131–132  | lubricant performance and, 62                              |
| thickening, 24, 76, 132 (figure), 133 (figure), 244.           | motor oil monitoring, 399                                  |
| See also film thickness; soot                                  | precision mechanics and, 381-382                           |
| viscosity, 115   | patch test, 407 (figure), 408 (figure)                     |
| See lubricants; engine oil                                     | pedal mechanism, 42  |
| oil aeration, 71 (table)                                       | Peklenik number, 5   |
| oil analysis. See engine oil, analysis                         | Pensky Martens Closed Cup (PMCC), 56                       |
| oil consumption, 73-74, 341. See also fuel consumption;        | percussive impact, 299 (figure)                            |
| fuel efficiency  | performance additive. See additive, performance            |
| oil control ring, 108  | performance specification. See performance standard        |
| oil filter, 207–208, 208 (figure), 427, 434–436                | performance standard organizations, 217, 226.              |
| oil filter tests, 429–430, 435–436. See also oil filter tests  | See also American Society for Testing and Materials        |
| oil pump, 109–110, 110 (figure), 126, 284 (figure)             | (ASTM); American Petroleum Institute (API); Euro-          |
| gear boxes and, 164  | pean Automobile Manufacturers' Association (ACEA);         |
| starvation of, 74, 76  | International Lubrication Standardization and              |
| spark ignition, 244. See also ISLAC GF-5                       | Approval Committee (ILSAC); specific organizations         |
| oil-out testing, 278   | performance standards, 61, 62 (figure), 75, 289–290        |
| olefin copolymers (OCPs), 24 (figure), 24–25                   | automatic transmission fluid (ATF) and, 266–26             |
| OM646 engine test, 232, 233–237                                | bearings and, 139  |
| open loop tests, 275–276                                       | biobased lubricants and, 466–467, 464 (table), 466 (table) |
| optical interferometry, 86–87                                  | engine oils and, 34–36, 36 (table ), 225–227, 226          |
| optical microscopy, 402, 407<br>optical soot meter, 410, 414   | (table), 227 (table)<br>heavy duty engines and, 233, 237   |
| organic contamination, 429                                     | manual transmission and, 289                               |
| original equipment manufacturers (OEM) standards, 34,          | methods and, 95, 430–431                                   |
| 36, 233, 266   | organizations, 66–67, 231–232, 237, 239–240, 244.          |
| degradation and, 64  | See also specific organizations                            |
| fuel efficiency and, 257                                       | passenger cars and, 233                                    |
| grease and, 43   | small-engine, 245–247, 250 (table), 250–251. See also      |
| o-rings, 397 (figure), 398 (figure)                            | motorcycle engine lubrication                              |
| oscillating friction tribometer, 397                           | systems of, 63–66  |
| Otto cycle, 119, 120 (figure)                                  | See also ACEA performance standards; API                   |
| outlet antidrain, 435  | performance standards; specific specifications             |
| overbased detergents, 34 (table)                               | phenates, 34 (table)                                       |
| overload, 275  | phosphates, 369, 370 (figure), 373                         |
| oxidation, 26-29, 68, 201, 337, 389 (figure), 403. See also    | phosphoric acid derivatives, 202                           |
| oxidative stability  | phosphorus, 78 (table) 78-79, 194, 209, 318                |
| oxidation inhibitor, 26, 201                                   | photoemission electron microscopy (PEEM), 363              |
| oxidative catalytic converter, 127                             | physical vapor deposition (PVD), 336, 342-343              |
| oxidative stability, 260, 319, 323–324, 325 (figure), 388,     | pinion, 179 (table), 180 (figure), 185                     |
| 413, 414 (figure), 456–457, 459, 460. See also aging           | damage and, 180, 184 (figure), 185                         |
| oxidative wear, 300  | tests and, 181, 182, 186                                   |
| D.   | torque and, 181 (figure)                                   |
| P  | piston, 105, 108, 122, 125–126                             |
| P/O atomic ratio, 370  | assembly, 338; 351, 352                                    |
| PAG46-4, 320 (table), 321, 322, 323 (table), 323–324, 325, 326 | coating, 340–341<br>deposits, 74                           |
| paraffinic oil, 41   | scuffing, 220–223, 224–225                                 |
| parasitic loss, 172  | sets, 106  |
| partial-load performance, 124                                  | velocity and, 122  |
| particle count, 402–403, 411, 412                              | See also piston ring; piston skirt                         |
| filtration and, 430, 432–433, 434, 435                         | piston pin joint, 108, 129                                 |
| wear and, 405–407, 407 (figure)                                | piston ring, 108, 109 (figure), 341–344, 343 (figure)      |
| See also particle counter                                      | material, 126  |
| particle counter, 402–403, 402 (figure), 403 (figure)          | See also piston ring tests                                 |
| particulate emissions, 126, 231                                | piston ring tests, 218–219, 219 (figure), 223–224, 225     |
| particulate filter, 318  | (figure), 228–229, 319, 347 (table)                        |
|  |  |

AST-MNL62-12-0501-IND.indd 490 01/10/12 6:57 PM

| piston scuffing test, 220–223                                 | R   |
|---|---|
| piston skirt, 109 (figure), 220–223, 338, 340–341             | radial isoprenes (RIs), 25                                    |
| piston-rings-to-cylinder block, 108                           | radial loader pneumatic mechanism (BVT-5), 147                |
| piston-skirt-to-cylinder block, 108                           | (figure)  |
| pitch point, 168, 169 (figure)                                | radiation scattering, 365                                     |
| pitting tests, 185 (figure), 185–186, 186 (figure), 187       | Raman spectrometer, 360, 365, 366 (figure). 366–367,          |
| planetary gears, 256 (figure), 380 (figure). See also         | 374 (figure)  |
| automatic transmission fluid (ATF), planetary                 | rancimat, 461   |
| gears and   | rate-of-change-based alarms, 411                              |
| plasma spray coating, 338, 339                                | RECESS, 311   |
| plastic contact, 302, 304                                     | reciprocating engine, 119, 121. See also internal combus-     |
| plastic deformation, 110, 309                                 | tion engine; engine   |
| plasticizer, 261, 265   | reciprocating test method, 97–98                              |
| plunge, 165–166   | resource conservation requirement, 245, 249 (table).          |
| plunging joint, 140   | See also environmental standards                              |
| pneumatic loader, 146 (figure)                                | reduction gears, 166  |
| point contact, 5, 6–7, 6 (figure), 303 (figure)               | reflection technique, 87                                      |
| point-contact elastohydrodynamic lubrication (EHL),           | reliability. See fatigue life                                 |
| 15, 87–88   | reliability environmental tester (RET), 149–152               |
| polar head groups, 262, 263                                   | renewable oil. <i>See</i> biofuel; mineral oil; vegetable oil |
| pollution control, 61–62. <i>See also</i> emissions; environ- |   |
|   | re-refined oil, 41  |
| mental standards  | resistance method, 85   |
| polutetrafluoethylene (PTFE), 340                             | resistance-capacitance oscillation, 86                        |
| polyacrylate rubber, 115 (table)                              | Reynolds equation, 11–12, 13, 16, 19, 90, 129, 131, 323       |
| polyalkyleneglycols (PAGs), 321, 386                          | rig/bench test, 134 (figure)                                  |
| polyalphaolefin (PAO), 35, 385                                | ring coating, 327–328   |
| polyglycols, 320, 321, 323, 325–326. See also PPG32-2;        | ring wear, 96   |
| PPG46-4   | road test, 273 dry-sump lubrication, 274, 276–278, 126        |
| polyimide (PI) surface, 383 (figure)                          | Romaszewski oil bench oxidation (ROBO) test, 61, 80,          |
| polyinternal olefin (PIO), 35                                 | 193 (table)   |
| polyisobutene (PIB), 24 (figure), 250                         | ROBO test, 61, 80, 193 (table)                                |
| polyisobutene (PIB) succinate, 31                             | roller follower wear test, 74, 197 (table), 198, 242 (table)  |
| polyisobutylene succinic anhydride (PIBSA), 31                | rolling, 296, 297 (table)                                     |
| polymer material, 382–383, 390–391, 390 (figure)              | Rolling Bearing–Test and Assessment for Life and              |
| polymers, 261–262, 394. See also polymer material             | Reliability, 149  |
| polymethacrylates (PMAs), 24 (figure), 25                     | rolling element bearings, 149–152, 167, 172, 173.             |
| polymethylsiloxane antifoam, 26 (figure)                      | See also hub bearings;  |
| polypropylene-glycol monobutylethers (PPGs), 321.             | rolling friction, 444–445, 445 (table), 446 (figure)          |
| See also specific polyglycols                                 | rolling speed, 87 (figure), 89 (figure), 91                   |
| polytetrafluor-ethtylene (PTFE), 144                          | rotary bench test methods, 96-97                              |
| polyurea, 142, 144  | rotary engine, 121, 379–380                                   |
| poppet valve, 107 (figure), 109                               | rotation generator, 380 (figure)                              |
| pore-blockage particle counter, 402–403, 403 (figure)         | rotation speed, 121   |
| pour point, 25 (figure), 52, 111, 200 (table), 262 (figure),  | rotor, 380 (figure)   |
| 457   | roughness, 4, 91–92, 92 (figure)                              |
| pour point depressant (PPD), 207                              | effect, 16, 18  |
| powder metallurgy, 346  | lubrication and, 89–90  |
| power, 105, 122, 123, 124, 169, 186, 187                      | route mean square (RMS), 4, 5                                 |
| power-law relationship, 87–88, 89 (figure)                    | surface and, 7, 9-10, 301 (figure), 304, 443 (table)          |
| power-on time, 383–384  | round-robin field tests, 420                                  |
| powertrain, 124–126, 157, 159, 351                            | route mean square (RMS) roughness, 4, 5. See also             |
| precision mechanics, 379–384                                  | roughness   |
| lubricants and, 384-391, 387 (figure), 388 (figure)           | rubber, 115 (figure)  |
| tribological simulation and, 392-398                          | rust inhibitor, 33, 48, 206–207, 264–265, 265 (figure)        |
| predictive alarms, 411–412                                    |   |
| pressure, 10, 11, 16–17, 126, 319, 322                        | S   |
| proactive alarms, 410   | SAE, 64, 237–239  |
| probability density function (PDF), 4                         | SAE HS 806, 435   |
| propeller ("PROP") shafts, 166                                | SAE J1260, 435  |
| propshaft, 42–43  | SAE J1488, 432  |
| pumping viscosity, 50   | SAE J1839, 432  |
| pure sliding friction, 443                                    | SAE J1858, 436  |

AST-MNL62-12-0501-IND.indd 491 01/10/12 6:57 PM

|   | 2777727  |
|---|--|
| SAE J1985, 432  | SKF ROF, 151 (figure)  |
| SAE J2793, 433  | SLBOCLE, 420   |
| SAE J300, 49, 67, 192, 238, 251 (table)                   | sliding bearings, 106  |
| SAE J306, 38 (table), 52                                  | sliding splines, 43  |
| SAE J310, 40  | sliding, 296, 297 (table), 304, 352, 384                     |
| SAE J905, 431–432   | slip-to-roll ratio, 443                                      |
| salicylates, 34 (table)                                   | slow-speed wear test, 181–183                                |
| sampling. See oil sampling methods                        | sludge, 76 (table), 205–206, 208–209, 208 (figure), 429      |
|   |  |
| sampling hardware, 400–401                                | (figure)   |
| Scanning Brookfield method, 50, 51                        | smooth surface lubrication, 89                               |
| scanning electron microscopy (SEM), 354–355, 355          | soap-thickened grease, 41                                    |
| (figure), 356 (figure). See also transmission electron    | SOFTC 2A, 430  |
| microscopy  | solid lubricant, 387   |
| scanning probe microscopy (SPM), 357                      | solubility relationships, 228                                |
| Schiff's reagent method, 414                              | solvent, 250   |
| scuff tests, 180–181, 181 (table), 220–225                | soot, 30–31, 32, 51, 231                                     |
| scuffing, 19, 420–422, 422 (table), 423                   | contamination, 296–299                                       |
| cold, 221, 225–227, 226 (table)                           | dispersancy, 414   |
| failures and, 180 (figure)                                | tests and, 244 (table), 429 (figure), 430                    |
| gears and, 178 (figure), 179 (figure)                     | See also ash; sooted oil                                     |
|   | sooted oil mini-rotary viscometer, 197 (table)               |
| measurement, 224–225, 421 (figure)                        |  |
| resistance, 327–328, 340–341                              | sooted oil, 72 (table), 72–73, 197 (table), 241 (table)      |
| test, 98-100, 100-101, 181 (figure). See also scuff tests | soybean oil, 457, 455, 457, 459–460                          |
| seal, 72, 106, 171 (figure), 196 (table), 285             | spacer layer, 86   |
| seal compatibility, 228, 242 (table), 260-261             | spark ignited engine, 119, 120, 122, 123-125, 123            |
| seal swell agents,48, 265                                 | (figure), 126, 127 (figure)                                  |
| sealed bearing simulation tester (ABDT), 152, 153         | specimen, 101 (figure), 102 (figure), 393 (figure)           |
| (figure)  | specimen holders, 100 (figure), 220, 222 (figure)            |
| sealed bearings, 147–149                                  | spherical contacts, 7  |
| seat adjuster, 43   | spindle hydraulic mechanism, 145 (figure)                    |
| seat insert valve, 344                                    | Splash lubrication, 126, 129                                 |
| seizure, 19   | spreading behavior, 387–388, 387 (figure), 388 (figure)      |
| selective catalytic reduction (SCR) device, 127           | spur gear, 110 (figure), 167, 168                            |
| self-cleaning filters, 435                                | square rig testing, 279                                      |
| Sequence IIIF, 196 (table), 197                           | SRV 4, 20 (table), 97–98, 220 (table), 221 (figure)          |
| Sequence IIIF, 242 (table)                                | SRV EP step-load test, 326                                   |
| Sequence IIIG, 191, 196 (table), 197                      | SRV test, 319, 324–325                                       |
| Sequence III-GA, 191, 194, 193 (table)                    | stainless steel, 407   |
| Sequence III-GB, 76, 111                                  | starter motors, 42   |
| Sequence IVA, 111, 192 (table), 194                       | start-stop-friction, 393–394                                 |
|   |  |
| Sequence IVA, 77  | static burst pressure, 435                                   |
| Sequence VG, 194  | static compatibility tests, 390                              |
| Sequence VIB, 194   | static friction, 393, 395 (figure)                           |
| Sequence VID, 111, 192                                    | static friction model, 446–448, 447 (figure)                 |
| Sequence VIII, 192, 193 (table), 194                      | static stress test, 390                                      |
| service intervals, 254, 293, 298                          | statistical alarms, 411                                      |
| service life, 410 (figure), 410–411                       | steel, 342, 343 (figure), 359 (figure), 368, 407             |
| shear loss, 251 (table)                                   | steering, 380  |
| shear rate, 49, 50–52, 68, 203 (figure). 324 (figure)     | stochastic modeling, 15                                      |
| shear stability, 69 (table), 80-81, 193 (table), 204, 241 | STP512, 289  |
| (table)   | stress cracking, 390 (figure)                                |
| shear stress, 10–11, 49, 50–51                            | Stribeck curve, 13 (figure), 14 (figure), 106 (figure), 215, |
| shear thinning, 10, 323                                   | 301, 352 (figure)  |
| shear-flow factors, 17 (table), 18 (table)                | stylus profilometer, 3                                       |
| shear-thinning model, 10                                  | substitution cycle, 120                                      |
| shifting clutch systems, 257                              | sulfated ash, 55, 72, 82                                     |
| shock absorber, 42  | sulfonates, 34 (table)                                       |
| silicone oils, 71, 386–387                                | sulfur, 78 (table) 78–79, 209, 239, 318, 370 (figure).       |
| silicone rubber (VMQ-1), 115 (figure), 193 (table)        | See also low-sulfur fuel                                     |
| silicon-based ceramics, 344                               | surface, 3–5, 6, 16 (figure)                                 |
| simulation reliability test, 152                          | deviation, 16 (figure)                                       |
| skewness, 4–5   | irregularities, 3, 4, 343                                    |
| onewhess, T-J   | 11105ulatities, 5, 7, 575                                    |

AST-MNL62-12-0501-IND.indd 492 01/10/12 6:57 PM

| modification, 333–338, 334 (figure), 338 (table). 342–344. <i>See also specific engine components</i> protection additive, 27–33, 41 | test sponsors, 64<br>tester. <i>See</i> bearing vibration tester; block-on-ring tester; <i>specific</i> test; <i>specific tool</i> ; test rig; wear tester |
|--|--|
| See also surface analysis; surface coating; surface treatment  | testing organizations. <i>See specific organizations</i> thermal conductivity, 382   |
| surface analysis, 3–5, 351–352, 353, 375   | thermal degradative conditions, 61   |
| application of, 367–375. See also specific applications  | thermal spray technology, 336 (table), 338, 339, 342   |
| chemical properties and, 360 (figure), 361 (figure), 362   | thermal wear, 300  |
| (figure), 364 (figure), 367 (figure)   | thermal-mechanical contact analysis, 8   |
| techniques, 354–367, 355 (figure), 356 (figure), 358   | thermodynamics, 119–121  |
| (figure). See also specific techniques   | thermoelasto hydrodynamic lubrication (TEHL), 131  |
| tools, 354 (figure), 355 (figure). See also specific tools   | thermogravimetric analysis (TGA), 431 (figure)   |
| surface coating, 8–9, 313, 333–337   | Thermo-Oxidation Engine Oil Simulation Test  |
| cylinders and, 338–430   | (TEOST-33C), 57  |
| pistons and, 340-344   | thickener, 24, 41, 76  |
| See also specific coating; specific treatments; surface  | three-body abrasive wear, 296, 298 (figure)  |
| treatment  | time of flight-secondary ion mass spectroscopy   |
| surface treatment, 133, 313 (figure), 333–336. See also  | (ToF)-SiMS, 364–365, 365 (figure), 370   |
| surface coating  | Timken antiwear test, 139  |
| SwRI Wear Index, 433 (figure)  | tin, 407   |
| synchromesh gear boxes, 161–164, 162 (table), 163  | Titan GT1 0W-20, 320, 321, 323 (table), 324, 325   |
| (figure), 167, 169–171, 170 (figure). See also synchromesh   | titanium aluminides, 344   |
| testing  | topographic structure, 5   |
| synchromesh testing, 279–280, 280 (figure)   | torque, 12, 123 (figure), 124, 125, 160, 274 (figure)  |
| synthetic esters. See esters   | measurement, 392 (figure)  |
| synthetic hydrocarbons, 385–387  | static, 446–448, 447 (figure), 450 (figure)  |
| Synthetic Oil Filter Contaminant (SOFTC) 2A, 430   | transmission and, 437–439  See also constant velocity CV joint. See also rolling   |
| synthetic oil, 35. See also engine oil   | element bearings   |
| Т  | torque converter, 56 (figure), 257, 259  |
| tachometer drive, 380 (figure)   | total base number (TBN), 82  |
| temperature, 9, 10, 23   | total friction model, 449–450  |
| additives and, 23, 30  | Total. See HTX 822 15W-50  |
| aging and, 390   | transducer positioning device, 145 (figure)  |
| bearings and, 129, 133 (figure)  | transfer gear box, 164   |
| corrosion and, 241 (table)   | transmission, 36, 157, 255–259, 258 (figure), 274,   |
| deposits and, 57, 79   | 289–290, 346   |
| drive train performance and, 171–172, 172 (figure)   | applied stress and, 275-276  |
| effects, 61, 62, 75, 80–81, 388  | efficiency, 171–172, 186   |
| engine performance and, 124 (figure)   | fluid, 37, 258,-259. See also automatic transmission   |
| flash point and, 55-56   | fluid (ATP); manual transmission; transmission   |
| friction and, 333, 334 (figure)  | fluid;   |
| oil and, 131–132, 260, 261 (figure)  | gears and, 345–346   |
| seals and, 285   | load and, 173–174  |
| surface treatments and, 333–336, 334 (figure); 336   | manual, 274–282  |
| (table)  | transverse, 162 (figure)   |
| synthetic hydrocarbons and, 385–387  | trends and, 160–161  |
| viscosity and, 50–51, 67–70, 203–204, 204 (figure)   | See also drivetrain; specific components; specific types;  |
| See also cooling tests; high-temperature corrosion bench test; low temperature   | transmission tests transmission electron microscopy (TEM), 356–357, 357  |
| temperature programmed desorption (TPD), 209   | (figure), 371 (figure)   |
| TEOST MHT, 192 (table)   | transmission fluids, 36–39, 40 (table). <i>See also</i> automatic  |
| TEOST-33C, 57, 79, 111–112, 192 (table)  | transition fluid (ATF); manual transmission fluid  |
| test components, 64, 65, 148, 149 (figure), 150. See also  | (MTF)  |
| specific test methods; specific tests; specimens   | transmission tests   |
| test gears, 179 (table), 179–180, 180 (figure), 185 (figure)   | ASTM specification and, 286–287 (table)  |
| test head, 148, 149 (fatigue), 150   | individual components, 279–287   |
| test methods, 49–57, 225–227, 226 (table), 227 (table).  | as a whole unit, 273–279   |
| See also specific ASTM methods performance   | transverse, 5 (figure), 162 (figure)   |
| standards  | trials. See bench tests; engine tests; laboratory tests; road  |
| test requirements. See engine tests  | tests; specific tests  |
| test rig 179 282 307 309 310 (figure)  | triaxial force transducer 339 (figure) 340 (figure)  |

AST-MNL62-12-0501-IND.indd 493 01/10/12 6:57 PM

| tribochemistry, 369–375, 372 (figure), 373 (figure), 376                              | of sooted oil, 51   |
|---|---|
| (figure)  | temperature and, 23–24, 51, 203–204, 204 (figure)   |
| tribological bench tests, 93–100, 96 (figure), 216 (figure),                          | test methods and, 49–52, 193 (table)  |
| 216–218; 217 (figure), 218 (figure). See also bench                                   | See also specific viscosity aspects. viscosity modifier   |
| testing; engine tests; laboratory tests; specific test                                | (VM)  |
| methods wear tests  | viscosity grades, 35 (table), 38 (table), 69, 205 (table), 288–289                                |
| tribotest categories, 306 (table)   | API and, 241  |
| trunk, 381  | in basestock, 47  |
| trygliycerides, 456<br>turbodiesel, 233   | SAE and, 240 (table) viscosity index (VI), 203, 259, 260 (table), 261–262, 317,                   |
| two-body abrasive wear, 296, 298 (figure)   | 321. <i>See also</i> viscosity modifier   |
| two-stroke engine, 119, 252–253   | viscosity laminar flow, 203 (figure)  |
| two-wheel drive, 159  | viscosity modifier (VM), 23–26, 24 (figure), 25 (figure),   |
|   | 111, 259, 261–262   |
| U   | viscosity tests, , 49-52, 193 (table), 244 (table), 412, 413,                                     |
| Ueda et al., 209  | 414–415   |
| unburnt hydrocarbons (HCs), 126   | viscosity-pressure relationship, 9–10, 11, 13   |
| United States, 455  | viscosity-temperature relationship, 9, 261 (figure), 391  |
| United States government, 110   | viscosity-temperature-pressure relationship, 10   |
| universal joints (UJs), 43  | Viscous drag, 201   |
| University of Northern Iowa National Ag-Based   | viscous stress tensor, 11   |
| Lubricants (NABL), 460, 461–462   | volatility, 53, 78, 79  |
| unsaturated fatty acids, 456  | volumetric compression ratio, 120   |
| V   | W   |
| vacuum plasma spraying (VPS), 343   | wall slip, 10   |
| vacuum sampling, 400–401 (figure)   | Walther equation, 9   |
| vacuum-based technique, 360-365   | Wankel engine, 121  |
| valve, 105-106, 107 (figure), 109, 308-311, 309 (figure),                             | warranty, 215, 273  |
| 311 (figure), 312 (figure)  | water contamination, 408, 430,432–433   |
| valvetrain, 106, 107, 216 (figure), 344-345   | water immersion, 278  |
| friction loss and, 352–353, 352 (figure)  | water separation, 428   |
| relief, 435   | water tester, 414   |
| wear, 73 (table), 77  | water tolerance, 56–57  |
| Van Doorne push belt, 259 (figure)  | wax crystals, 262   |
| varnish, 205  | wax formation, 207  |
| varnish test, 76 (table)  | wear, 192 (table), 297 (table), 301 (table)   |
| Veeco software, 101, 102 (figure) vegetable oil, 41, 254, 455–459                     | alternative fluids and, 325–326, 328<br>analysis, 293–295, 294 (figure), 294 (table), 295 (table) |
| genetic modification and, 459–460   |   |
| temperature and, 459, 465   | 297 (table)<br>bearings and, 134–135, 135 (figure)  |
| See also biofuel  | coefficients, 306 (figure), 306 (table)   |
| velocity. See angular velocity  | contact mechanics and, 302–304, 305 (figure)  |
| velocity, see alignal velocity<br>velocity joints. See constant velocity joints (CVJ) | control, 198–201. See also zinc dialkyl dithiophosphate   |
| velocity tests, 144–146, 144 (figure), 145 (figure), 146                              | (ZDDP)  |
| (table), 147 (table)  | debris, 402, 412  |
| vibration, 434 (table), 434 (figure), 435, 437  | engine, 73, 76, 78  |
| vibration fatigue test, 435   | failures, 182   |
| vibrational spectroscopy technique, 365–367, 367                                      | ferrous density and, 405-406, 406 (figure)  |
| (figure)  | map, 304–305, 305 (figure)  |
| VII, 48, 49, 51, 204  | mechanisms of, 110  |
| viscoelastic constitutive equation, 10  | modeling, 294, 304-305, 305 (table), 310-311, 314   |
| viscosimetrics, 24, 49, 319   | particles and, 405-407, 406 (figure), 412   |
| viscosity, 202 (figure), 267 (table), 403   | pistons and, 340  |
| classification and, 237-239, 412  | precision mechanics and, 394-396, 396 (figure), 397   |
| control, 202–203, 200 (table)   | (figure), 398 (figure)  |
| cranking, 49–50   | rate, 300–301, 300 (figure), 327  |
| diesel fuel and, 419 (figure)   | reduction, 312 (table), 312–313, 313 (figure)   |
| loss, 262   | scar, 370   |
| measurements, 67–69, 324 (figure)   | tester, 96–97, 97 (figure), 98 (figure), 100  |
| relationships, 9–11   | valvetrain, 73 (table), 77, 295 (figure)  |
| requirements, 78–82, 112  | See also wear tests   |

```
wear test rig, 97, 100
                                                               x-ray absorption near-edge structure (XANES)
wear tests, 305–308, 307 (figure), 307 (table), 308 (figure)
                                                                  spectroscopy, 199, 200
    analysis, 293–295, 294 (figure), 294 (table), 295 (figure)
                                                               x-ray absorption spectra (XAS), 362
    measurement and, 218 (figure), 223-224, 223 (figure),
                                                                x-ray photoelectron spectroscopy (XPS), 361 (figure),
                                                                  361-362, 362 (figure), 369
    pistons and, 218-219, 220, 225 (figure)
                                                                x-ray photoemission electron microscopy (X-PEEM),
    in service oil, 406 (figure)
                                                                  363-364, 364 (figure
    slow speed, 181-183, 182 (table), 183 (figure)
                                                                x-ray transmission method, 85
    test methods and, 96-102, 298-299
    See also slow-speed wear test
                                                               Zhu, D., 89, 90
Weierstrass-Mandelborot (M-W), 10
wet clutch performance, 251
                                                                zinc dialkyl dithiophosphate (ZDDP), 30, 48, 198-201,
wet-stump circulating system, 400 (figure)
                                                                  369-371, 369 (figure), 370 (figure), 371 (figure)
wetting modifiers, 38
                                                                    biodiesel and, 209
wheel bearing, 42, 43, 44
                                                                    corrosion and, 207
wheel bearing grease, 467
                                                                    diesel engines and, 191
white-light interferometer, 3
                                                                    friction modification and, 220
window winder, 42
                                                                    MoDTC and, 202, 206, 224
World War II, 64
                                                                    phosphorus and, 191, 194
                                                                    Al-Si alloy and, 373-374
                                                                zinc phosphates, 369-370, 370 (figure). See also zinc
x-ray absorption near-edge structure (XANES), 362–363,
                                                                  dialkyl dithiophosphate (ZDDP)
  363 (figure), 364 (figure), 370–371, 371 (figure)
```

AST-MNL62-12-0501-IND.indd 495 01/10/12 6:57 PM