

WOODHEAD PUBLISHING IN MATERIALS



The science and technology of materials in automotive engines

Hiroshi Yamagata



WP

Contents

	<i>Preface</i>	<i>xi</i>
1	Engines	1
1.1	The reciprocating engine	1
1.1.1	The four-stroke engine	2
1.1.2	The two-stroke engine	3
1.1.3	The diesel engine	4
1.2	Advantages and disadvantages of reciprocating engines	5
1.3	Engine components and typical materials	5
1.3.1	Components	5
1.3.2	Typical materials	6
1.4	Recent trends in engine technology	7
1.5	References and notes	9
2	The cylinder	10
2.1	Structures and functions	10
2.2	The cast iron monolithic block	15
2.2.1	Honing, lubrication and oil consumption	17
2.2.2	Improvement of wear resistance of cast iron blocks	22
2.3	The compact graphite iron monolithic block	22
2.4	Aluminum blocks with enclosed cast iron liners to improve cooling performance	25
2.5	Thermal distortion and heat discharge	29
2.5.1	How does the cylinder enclosing a press-fit liner deform with heat?	29
2.5.2	Powder metallurgical aluminum liner improves heat transfer	30
2.6	Improving engine compaction with surface modifications	32
2.6.1	Shortening the bore interval	32
2.6.2	Chromium plating	32
2.6.3	Ni-SiC composite plating	33
2.6.4	Thermal spray	37

2.6.5	The hyper-eutectic Al-Si block	37
2.6.6	Cast-in composite	39
2.7	Casting technologies for aluminum cylinder blocks	40
2.7.1	Sand casting	42
2.7.2	Lost foam process	43
2.7.3	High-pressure die casting	43
2.7.4	Gravity die casting	45
2.7.5	Low-pressure die casting	45
2.7.6	Squeeze die casting	46
2.8	Open and closed deck structures	46
2.9	The two-stroke-cycle engine cylinder	48
2.10	Conclusions	49
2.11	References and notes	51
3	The piston	53
3.1	Structures and functions	53
3.1.1	Function	53
3.1.2	The use of Si to decrease the thermal expansion of aluminum	58
3.2	Manufacturing process	59
3.2.1	Casting	59
3.2.2	Modifying the distribution of Si crystal	62
3.3	Piston design to compensate thermal expansion	65
3.4	Heat treatment	68
3.4.1	Age hardening and age softening	68
3.4.2	Hardness measurement estimates the piston temperature during operation	70
3.5	Reinforcement of the piston ring groove	72
3.6	The high-strength piston	76
3.6.1	Strength of piston materials at high temperatures	76
3.6.2	The lightweight forged piston	77
3.6.3	Powder-metallurgical aluminum alloy raises high-temperature strength	80
3.6.4	The iron piston	81
3.7	Conclusions	83
3.8	References and notes	84
4	The piston ring	87
4.1	Functions	87
4.2	Suitable shapes to obtain high power output	89
4.3	Ring materials	95
4.3.1	Flaky graphite cast iron	95

4.3.2	Use of spherical graphite cast iron to improve elastic modulus and toughness	98
4.3.3	Using steel to generate lightweight rings	99
4.4	Designing the self-tension of rings	103
4.4.1	The distribution of contact pressure and tension	102
4.4.2	Tensioning	104
4.5	Surface modification to improve friction and wear	104
4.5.1	Surface modifications during running-in	104
4.5.2	Surface modifications to improve durability	106
4.6	Conclusions	108
4.7	References and notes	108
5	The camshaft	110
5.1	Functions	110
5.2	Tribology of the camshaft and valve lifter	113
5.3	Improving wear resistance of the cam lobe	116
5.3.1	Chilled cast iron	116
5.3.2	Analysis of chemical composition of cast iron before pouring	123
5.3.3	Finishing – boring and grinding	125
5.3.4	Composite structures	126
5.4	Reducing friction in the valve train	128
5.5	Conclusions	130
5.6	References and notes	131
6	The valve and valve seat	132
6.1	Functions	132
6.2	Alloy design of heat-resistant steels	134
6.2.1	Martensitic steel	134
6.2.2	Austenitic steel	136
6.3	The bonded valve using friction welding	139
6.4	Increasing wear resistance	143
6.4.1	Stellite coating	143
6.4.2	The Ni-based superalloy valve	143
6.5	Lighter valves using other materials	145
6.5.1	Ceramics	145
6.5.2	Titanium alloys	145
6.6	The valve seat	147
6.7	Conclusions	150
6.8	References and notes	150
7	The valve spring	152
7.1	Functions	152

7.2	Steel wires	154
7.3	Coiling a spring	156
7.4	Improving fatigue strength by shot peening	158
7.5	The cylinder head	161
7.6	Conclusions	163
7.7	References and notes	163
8	The crankshaft	165
8.1	Functions	165
8.2	Types of crankshaft	166
	8.2.1 The monolithic crankshaft	166
	8.2.2 The assembled crankshaft	169
8.3	Rigidity	170
8.4	Forging	170
	8.4.1 Deformation stress	170
	8.4.2 Recrystallization and recovery	171
	8.4.3 Hot forging	173
	8.4.4 Cold and semi-hot forging	175
	8.4.5 Combination forging	178
8.5	Surface-hardening methods	178
	8.5.1 Carburizing	178
	8.5.2 Nitriding	187
	8.5.3 Nitrocarburizing	188
	8.5.4 Carbonitriding	189
	8.5.5 Ion nitriding	190
	8.5.6 Induction hardening	191
8.6	Micro-alloyed steel	194
8.7	Strengthening	198
8.8	Conclusions	204
8.9	References and notes	204
9	The connecting rod	207
9.1	Functions	207
9.2	The monolithic con-rod	209
9.3	The needle roller bearing	212
	9.3.1 Fatigue failure	212
	9.3.2 Factors affecting the life of bearings	215
	9.3.3 Secondary refining after steel-making	217
9.4	The assembled con-rod	218
	9.4.1 Structure and material	218
	9.4.2 The con-rod bolt	218
9.5	The plain bearing	222
9.6	Fracture splitting	224

9.7	Conclusions	226
9.8	References and notes	226
10	The catalyst	228
10.1	The development of catalysts for petrol engines	228
10.2	Structures and functions	229
10.3	The three-way catalyst	232
	10.3.1 Oxidation, reduction and three-way catalysts	232
	10.3.2 Deterioration of catalysts	233
10.4	The honeycomb substrate	235
	10.4.1 Ceramic	235
	10.4.2 Metal	235
10.5	The development of catalysts to reduce NO _x	238
10.6	Controlling pollutants at cold start	239
	10.6.1 Reducing heat mass and back-pressure	239
	10.6.2 The close-coupled catalytic converter	239
10.7	On-board diagnosis	241
10.8	Exhaust gas after-treatment for diesel engines	241
	10.8.1 Diesel particulate filters	241
	10.8.2 Regenerative methods	244
	10.8.3 Expendable catalyst additive	245
	10.8.4 The deNO _x catalyst	245
10.9	Conclusions	246
10.10	References and notes	246
11	The turbocharger and the exhaust manifold	248
11.1	Functions of the turbocharger	248
11.2	The turbine wheel	249
	11.2.1 Turbine and compressor designs	249
	11.2.2 Investment casting	252
11.3	The turbine housing	256
	11.3.1 Cast iron	255
	11.3.2 Cast steel	255
11.4	The exhaust manifold	256
11.5	Conclusions	260
11.6	References and notes	260
	Glossary	261
	Appendices	265
A	International standards conversion table for alloys	265
B	Function analysis table	267
C	The phase diagram	269

x Contents

D	Types of cast iron	275
E	Steel-making and types of steel	279
F	Creating various properties through heat treatment	282
G	Mechanisms for strengthening metals	288
H	Surface modification	292
I	Joining technology	297
J	Aluminium casting	299
K	Elastic deformation and plastic deformation	305
L	Metal matrix composites in engines	307
	Index	309