MODERN CONCRETE TECHNOLOGY 3

CONCRETE IN HOT ENVIRONMENTS

I. SOROKA

E & FN SPON
An Imprint of Chapman & Hall

Contents

Foreword vii
Preface ix
Acknowledgements xi

1 Portland Cement
1.1 Introduction 1
1.2 Major constituents 2
1.2.1 Alite 2
1.2.2 Belite 3
1.2.3 Tricalcium aluminate 3
1.2.4 Celite 3
1.2.5 Summary 4
1.3 Minor constituents 6
1.3.1 Gypsum ($CaSO_4 \cdot 2H_2O$) 6
1.3.2 Free lime (CaO) 11
1.3.3 Magnesia (MgO) 11
1.3.4 Alkali oxides (K_2O, Na_2O) 12
1.4 Fineness of the cement 12
1.5 Different types of Portland cement 13
1.5.1 Rapid-hardening cement (RHPC) 14
1.5.2 Low-heat cement (LHPC) 15
1.5.3 Sulphate resisting cement (SRPC) 16
1.5.4 White and coloured cements 17
1.6 Summary and concluding remarks 18
References 19

2 Setting and Hardening

2.1 Introduction . . . 21
2.2 The phenomena . . . 21
2.3 Hydration . . . 23
2.4 Formation of structure . . . 25
2.5 Effect of temperature on the hydration process . . . 28
2.5.1 Effect on rate of hydration . . . 28
2.5.2 Effect on ultimate degree of hydration . . . 30
2.5.3 Effect on nature of the hydration products . . . 31
2.5.4 Effect on structure of the cement gel . . . 32
2.6 Effect of temperature—practical implications . . . 34
2.6.1 Effect on setting times . . . 34
2.6.2 Effect on rate of stiffening . . . 35
2.6.3 Effect on rise of temperature . . . 35
2.7 Summary and concluding remarks . . . 37
References . . . 38

3 Mineral Admixtures and Blended Cements

3.1 Mineral admixtures . . . 41
3.1.1 Low-activity admixtures . . . 42
3.1.2 Pozzolanic admixtures . . . 42
3.1.2.1 Pozzolanic activity . . . 42
3.1.2.2 Classification . . . 43
3.1.2.2.1 Pulverised fly-ash (PFA) . . . 43
3.1.2.2.2 Condensed silica fume (CSF) . . . 45
3.1.2.3 Effect on cement and concrete properties . . . 47
3.1.2.3.1 Heat of hydration . . . 47
3.1.2.3.2 Microstructure . . . 50
3.1.2.3.3 Calcium hydroxide content and pH value of pore water 51
3.1.2.3.4 Strength development . . . 51
3.1.2.3.5 Other properties . . . 54
3.1.3 Cementitious admixtures . . . 54
3.1.3.1 Blast-furnace slag . . . 55
3.1.3.2 Effect on cement and concrete properties . . . 58
3.1.3.2.1 Heat of hydration . . . 58
3.1.3.2.2 Microstructure . . . 58
3.1.3.2.3 Strength development . . . 59
3.1.3.2.4 Other properties . . . 60

3.1.4 Summary 61
3.2 Blended cements 61
3.2.1 Definition and classification 61
3.2.2 Properties 62
3.3 Summary and concluding remarks 66
References 67

4 Workability
4.1 Introduction 69
4.2 Factors affecting water demand 70
4.2.1 Aggregate properties 70
4.2.2 Temperature 72
4.3 Factors affecting slump loss 73
4.3.1 Temperature 73
4.3.2 Chemical admixtures 75
4.3.2.1 Classification 75
4.3.2.2 Water-reducing admixtures 76
4.3.2.3 Retarding admixtures 76
4.3.2.4 Superplasticisers 78
4.3.3 Fly-ash 80
4.3.4 Long mixing and delivery times 81
4.4 Control of workability 84
4.4.1 Increasing initial slump 86
4.4.2 Lowering concrete temperature 86
4.4.2.1 Use of cold water 87
4.4.2.2 Use of ice 88
4.4.2.3 Use of cooled aggregate 89
4.4.3 Retempering 90
4.4.3.1 Retempering with water 91
4.4.3.2 Retempering with superplasticisers 93
4.5 Summary and concluding remarks 97
References 98

5 Early Volume Changes and Cracking
5.1 Introduction 101
5.2 Plastic shrinkage 101
5.2.1 Factors affecting plastic shrinkage 104
5.2.1.1 Environmental factors 105

5.2.1.2 Cement and mineral admixtures . . . 108
5.2.1.3 Water content . . . 110
5.2.1.4 Chemical admixtures . . . 111
5.2.1.5 Fibre reinforcement . . . 111
5.2.2 Plastic shrinkage cracking . . . 112
5.3 Plastic settlement and cracking . . . 114
5.4 Summary and concluding remarks . . . 115
References . . . 116

6 Concrete Strength

6.1 Introduction . . . 119
6.2 Strength of hardened cement paste . . . 119
6.2.1 Effect of W/C ratio on initial porosity . . . 120
6.2.2 Combined effect of W/C ratio and degree of hydration on porosity . . . 120
6.2.3 Effect of W/C ratio on strength . . . 121
6.3 Strength of paste–aggregate bond . . . 122
6.3.1 Effect of W/C ratio . . . 122
6.3.2 Effect of surface characteristics . . . 122
6.3.3 Effect of chemical composition . . . 123
6.3.4 Effect of temperature . . . 123
6.4 Effect of aggregate properties and concentration on concrete strength . . . 124
6.4.1 Effect of aggregate strength . . . 125
6.4.2 Effect of aggregate modulus of elasticity . . . 127
6.4.3 Effect of particle size . . . 127
6.4.4 Effect of aggregate concentration . . . 128
6.4.5 Summary . . . 129
6.5 Strength–W/C ratio relationship . . . 129
6.6 Effect of temperature . . . 131
6.6.1 Internal cracking . . . 134
6.6.2 Heterogeneity of the gel . . . 136
6.6.3 Type of cement . . . 137
6.7 Summary and concluding remarks . . . 138
References . . . 139

7 Drying Shrinkage

7.1 Introduction . . . 143
7.2 The phenomena . . . 144
7.3 Shrinkage and swelling mechanisms . . . 144
7.3.1 Capillary tension . . . 145
7.3.2 Surface tension . . . 145

7.3.3 Swelling pressure . . . 147
7.3.4 Movement of interlayer water . . . 147
7.4 Factors affecting shrinkage . . . 148
7.4.1 Environmental factors . . . 148
7.4.2 Concrete composition and properties . . . 152
7.4.2.1 Aggregate concentration . . . 152
7.4.2.2 Rigidity of aggregate . . . 153
7.4.2.3 Cement content . . . 155
7.4.2.4 Water content . . . 155
7.4.2.5 W/C ratio . . . 155
7.4.2.6 Mineral admixtures . . . 156
7.5 Shrinkage cracking . . . 159
7.6 Summary and concluding remarks . . . 160
References . . . 161

8 Creep

8.1 Introduction . . . 163
8.2 The phenomena . . . 164
8.3 Creep mechanisms . . . 165
8.3.1 Swelling pressure . . . 165
8.3.2 Stress redistribution . . . 166
8.3.3 Movement of interlayer water . . . 166
8.3.4 Concluding remarks . . . 167
8.4 Factors affecting creep . . . 167
8.4.1 Environmental factors . . . 167
8.4.2 Concrete composition and properties . . . 170
8.4.2.1 Aggregate concentration and rigidity . . . 170
8.4.2.2 Strength, stress and stress to strength ratio . . . 172
8.4.2.3 Moisture content . . . 173
8.4.2.4 Mineral admixtures . . . 174
8.5 Summary and concluding remarks . . . 174
References . . . 176

9 Durability of Concrete

9.1 Introduction . . . 179
9.2 Permeability . . . 180
9.2.1 Effect of water to cement (W/C) ratio . . . 180
9.2.2 Effect of temperature . . . 183
9.2.3 Summary and concluding remarks . . . 185
9.3 Sulphate attack . . . 185

9.3.1 Mechanism . . . 186
9.3.2 Factors affecting sulphate resistance . . . 186
9.3.2.1 Cement composition . . . 186
9.3.2.2 Cement content and W/C ratio . . . 187
9.3.2.3 Pozzolans . . . 188
9.3.2.4 Blast-furnace slag . . . 190
9.3.2.5 Temperature . . . 191
9.3.3 Controlling sulphate attack . . . 192
9.4 Alkali–aggregate reaction . . . 193
9.4.1 Reactive aggregates . . . 194
9.4.2 Effect of temperature . . . 195
9.4.3 Controlling alkali–silica reaction . . . 195
References . . . 198

10 Corrosion of Reinforcement

10.1 Introduction . . . 201
10.2 Mechanism . . . 203
10.3 Corrosion of steel in concrete . . . 205
10.4 Carbonation . . . 205
10.4.1 Factors affecting the rate of carbonation . . . 207
10.4.1.1 Environmental conditions . . . 207
10.4.1.2 Porosity of concrete cover . . . 209
10.4.1.3 Type of cement and cement content . . . 209
10.4.1.4 Practical conclusions . . . 211
10.5 Chloride penetration . . . 212
10.5.1 Factors affecting rate of chloride penetration . . . 213
10.5.1.1 Porosity of concrete cover . . . 213
10.5.1.2 Type of cement and cement content . . . 214
10.5.1.3 Temperature . . . 217
10.5.1.4 Corrosion inhibitors . . . 218
10.6 Oxygen penetration . . . 219
10.7 Effect of environmental factors on rate of corrosion . . . 220
10.8 Effect of cement type on rate of corrosion . . . 222
10.9 Practical conclusions and recommendations . . . 224
References . . . 227

List of Relevant Standards . . . 231
Selected Bibliography . . . 233
Author Index . . . 235
Subject Index . . . 243