

CONTENTS

1

Introduction	3
1.1 Preamble	3
1.2 Why mine fill?	3
1.2.1 Ensuring long-term regional stability	4
1.2.2 Limiting excavation exposure	5
1.2.3 Waste disposal	6
1.3 Considerations for selection of mine fill systems	6
1.4 Brief history of mine fill	8
1.4.1 Australian mine fill history	8
1.4.2 North American mine fill history	8
1.4.3 Recent mine fill history	9

2

Basic Mine Fill Materials	13
2.1 Preamble	13
2.2 Tailings	13
2.2.1 Sizing	13
2.2.2 Mineralogy	14
2.2.3 Particle shape	14
2.2.4 Tailings oxidation	14
2.3 Natural sands	15
2.4 Rock and aggregate	15
2.4.1 Aggregate grading	15
2.4.2 Attrition	15
2.5 Water	16
2.6 Cement	17
2.6.1 Chemical reactions	17
2.6.2 Cement contents	18
2.7 Pozzolans	18
2.7.1 Fly ash	18
2.7.2 Slag	19
2.7.3 Gypsum	19
2.7.4 Other pozzolans	19
2.7.5 Admixtures	19

3

Geomechanics of Mine Fill	23
3.1 Preamble	23
3.2 Soil mechanics and mine fill	24
3.3 Mine backfilling applications and the relevant fill parameters	24
3.3.1 Dry fill (DF)	24
3.3.2 Hydraulic fill (HF)	24
3.3.3 Cemented hydraulic fill (CHF)	24
3.3.4 Paste fill	24
3.3.5 Composite fills	24
3.3.6 Shotcrete	25
3.3.7 Geofabrics — geotextiles	25
3.4 Sources of mine fill tailings	26
3.4.1 Mine tailings	26
3.4.2 Phases of backfill materials	26
3.5 Some volumetric relationships	26
3.5.1 Degree of saturation	28
3.5.2 Some important unit weights of backfill materials	28
3.5.3 Water content of fill	29
3.5.4 Moisture content of fill	29
3.5.5 Solids content	29
3.5.6 Saturated fills, slurries and pastes	29
3.5.7 The volumetric solids concentration C_v	30
3.6 Particle size distribution of backfill/tailings	31
3.6.1 Particle size distribution curve	31
3.6.2 Uniformity of fill	32
3.6.3 Some important benchmarks on particle packing	33
3.6.4 Relative density or density index	33
3.7 Atterberg's limits	34
3.7.1 Ultra fines in tailings ($<2\ \mu\text{m}$)	35
3.8 The fundamentals of the shear strength of backfill	36
3.9 Fill permeability(hydraulic conductivity)	37
3.9.1 Determination of coefficient of permeability	37
3.9.2 Seepage gradient	38
3.9.3 Quick condition and piping	38
3.9.4 Development of piping in fill masses	38
3.9.5 Liquefaction of mine fill	38
3.10 Compaction and consolidation of mine fill	39
3.10.1 Consolidation of fill	39
3.11 Shear strength of fill	40
3.11.1 Effective stress concept	40
3.11.2 Shear strength	40
3.11.3 Some general observations regarding strength development in cemented fills	41
3.11.4 Measurement of shear strength	42
3.12 Lateral earth pressure	43
3.13 Arching in fill masses and stability analyses	44
3.13.1 Slope fill mass stability analysis — 3D wedge analysis	45

4

Fluid Mechanics of Mine Fill	51
4.1 Preamble	51
4.2 Transport and delivery of fill slurries	51
4.2.1 Introduction to fluid mechanics principles	52
4.2.2 Hydraulic fill slurry behaviour	52
4.2.3 Paste fill behaviour	53
4.2.3.1 Paste fill rheology	53
4.2.3.2 Paste fill flow in pipes and wall shear stress	53
4.2.3.3 Yield shear stress — effect of pulp density	54
4.3 Reticulation design	54
4.3.1 Hydraulic fill reticulation design	55
4.3.2 Calculating friction system losses in hydraulic fill systems	56
4.3.3 Paste fill reticulation design	57
4.3.3.1 Calculating friction factors in paste fill systems	57
4.3.3.2 Flow control strategy	57
4.4 Drainage through hydraulic fill	59
4.4.1 Drainage analysis	59
4.4.2 Saturation	59
4.5 Testing and measurements	60
4.5.1 Laboratory-scale rheology	60
4.5.1.1 Yield shear stress and slump test	60
4.5.1.2 Yield shear stress determined by the vane shear viscometer	61
4.5.1.3 Viscosity measurement	61
4.5.1.4 Pipe loop testing	62

5

Introduction to Hydraulic Fill	67
5.1 Preamble	67
5.2 Design	68
5.2.1 Demand from mining methods	68
5.2.1.1 Cemented or uncemented hydraulic fill?	68
5.2.2 Supply of materials	68
5.2.2.1 Mill tailings	68
5.2.2.2 Natural surface sand deposits	69
5.2.2.3 Binders	69
5.2.3 Preparation of hydraulic fill	69
5.2.3.1 Tailings dewatering	69
5.2.3.2 Tailings desliming	70
5.2.3.3 Fill permeability and percolation rate	70
5.2.3.4 Empirical relationships for permeability/percolation rate of hydraulic fill	70
5.2.3.5 Particle size distribution curves	70
5.2.3.6 Cautionary note on sizing criteria for hydraulic fill	71
5.2.3.7 Hydrocyclones	71
5.2.3.8 Spiral and rake classifiers	72
5.2.3.9 Drum filters	72
5.2.3.10 Elutriation tanks	72
5.2.3.11 Storage tanks and pachucas	72

5.2.4	Delivery systems from preparation site to stope.....	72
5.2.5	Fill containment — design and construction of fill barricades.....	73
5.2.6	Placement and drainage.....	74
5.2.6.1	Design principles.....	75
5.2.7	The risk of fill inrush.....	76
5.2.7.1	Erosion piping failure mechanism.....	76
5.2.7.2	Mechanical defects — design, construction.....	76
5.3	Monitoring and performance.....	77
5.3.1	Operational monitoring of fill and barricades.....	77
5.4	Hydraulic fill — summary of key issues.....	78

6

Paste Fill.....	83
6.1 Preamble.....	83
6.2 Principles.....	83
6.2.1 Advantages of paste.....	85
6.2.2 Considerations with paste.....	85
6.3 Demands from mining methods.....	85
6.3.1 Paste fill performance.....	85
6.3.2 Rate of filling.....	86
6.3.2.1 Placement rates.....	86
6.4 Supply of materials.....	86
6.4.1 Tailings.....	86
6.4.2 Water.....	86
6.4.3 Binder.....	87
6.4.4 Coarse fraction.....	87
6.5 Processing of components.....	87
6.5.1 Tailings dewatering.....	87
6.5.1.1 Thickening.....	88
6.5.1.2 Filtration.....	88
6.5.1.3 Excavated tailings.....	88
6.5.2 Mixing.....	89
6.5.3 Binder addition.....	89
6.5.4 Mix control.....	90
6.6 Delivery and placement.....	90
6.6.1 Boreholes.....	90
6.6.2 Pipes.....	90
6.6.3 Pumps.....	91
6.6.4 Flushing of distribution system.....	91
6.7 Retention.....	92
6.8 Design.....	92
6.8.1 Material characterisation.....	92
6.8.2 Flow characteristics.....	93
6.8.2.1 Pump test.....	93
6.8.3 Strength gain.....	93
6.8.3.1 Results.....	93
6.8.3.2 Effect of yield stress at high cement contents.....	94
6.8.4 Dewatering testwork.....	94
6.8.4.1 Thickener design.....	94
6.8.4.2 Filtration design.....	94
6.9 Monitoring and performance.....	94
6.10 Examples of paste fill applications.....	95

7

Rock Fill in Mine Fill	101
7.1 Preamble	101
7.2 Angle of repose	101
7.3 Unmodified rock fill	101
7.4 Modified rock fill	102
7.5 Dilating fills	102
7.6 Contracting fills	103
7.7 Particle size optimisation	103
7.8 Blending of rock fill	105
7.9 Some standard rock fill gradings	106
7.10 Binder addition	106
7.11 Inclusion of fine-grained materials	106
7.12 Friction angle of rock fill	107
7.13 Rock fill production	107
7.14 Delivery of rock fill in mining	108
7.14.1 Cemented rock fill at Mount Isa Mines	108
7.14.2 Fill mass stability	108
7.15 Cement slurry rock fill trials at Mount Isa Mines (MIM) in 1996	108
7.15.1 Large cylinder testing	108
7.15.2 Water content of the mix	108
7.15.3 Composition of the final placed CSRF	108
7.15.4 Strength	110
7.15.5 Fill placement trials	110
7.16 Rocky Paste Fill (RPF) trials at Mount Isa Mines in 1996	111
7.16.1 RPF mix components	111
7.16.2 RPF strength	112
7.16.3 Quality of RPF after placement	112
7.16.4 Design chart for RPF	112
7.16.5 Advantages of RPF	112
7.17 Rocky paste fill at Olympic Dam Mine	112
7.18 CSAF at George Fisher Mine	114

8

Other Fill Types and Practices	119
8.1 Preamble	119
8.2 Fill in underground coal mines	121
8.2.1 Preamble	121
8.2.2 Background	121
8.2.3 Ongoing development	123
8.3 Surface subsidence mitigation and prevention	123
8.3.1 Preamble	123
8.3.2 Plant and equipment	124
8.3.3 Fill material	124
8.3.4 Water supply	124
8.3.5 Fill containment	124
8.3.6 Fill delivery boreholes and surface plant	124
8.3.7 Fill preparation and placement	125
8.3.8 Monitoring	126
8.3.9 Project performance	126

8.4 Filling metalliferous and coal open pits	126
8.4.1 Preamble	126
8.4.2 Fill materials and filling	126
8.4.3 Fill materials in more detail	126
8.4.3.1 Waste rock or coarse coal reject	126
8.4.3.2 Tailings, fine coal reject and fly ash	126
8.4.3.3 Co-disposal	127
8.4.4 Metalliferous mining	127
8.4.5 Coal mining	127
8.4.6 Water management	127
8.4.7 Waste rock stability	127
8.4.8 Submerging tailings	127
8.4.9 Mine closure	127
8.4.10 Safety and hazard reduction	127
8.5 Co-disposal of mining and municipal wastes	128
8.5.1 Preamble	128
8.5.2 Handling municipal waste	128
8.5.2.1 Transportation	128
8.5.2.2 Mine void access	128
8.5.3 Co-disposal	128
8.5.4 Dumped co-disposal	128
8.5.5 Pumped tailings/fine reject	128
8.5.6 Design	128
8.5.7 Liner	128
8.5.8 Underdrains	129
8.5.9 Safety and hazard reduction	129
8.6 Use of completed open pits for tailings disposal	129
8.6.1 Preamble	129
8.6.2 Economics	129
8.6.3 Environmental requirements	129
8.6.4 Physical characterisation	129
8.6.5 Water removal/recovery systems	130
8.6.6 Geochemical characterisation	131
8.6.7 Geotechnical considerations	132
8.6.8 Rehabilitation	132
8.7 Cemented aggregate fill in complex ore bodies	132
8.7.1 Preamble	132
8.7.2 Geology	132
8.7.3 Ground conditions	132
8.7.4 Mining method	132
8.7.5 Cemented aggregate fill	133
8.7.5.1 Evaluation and test work	133
8.7.5.2 Parameters	133
8.7.5.3 Evaluation approach	134
8.7.6 Operational issues	134
8.8 A review of some important aspects of cemented aggregate fill	134
8.8.1 Preamble	134
8.8.2 Particle size distribution	134
8.8.3 Fill placement	135
8.8.4 Fill quality test work	136
8.8.4.1 Aggregate quality	136
8.8.4.2 Aggregate particle size distribution	136
8.8.4.3 Aggregate moisture content	136
8.8.4.4 Binder strength	136
8.8.4.5 Slump tests	136
8.8.4.6 CAF reference cylinder strength tests	136
8.8.4.7 Sands and tailings	136
8.8.5 In situ assessment of CAF	137
8.8.5.1 Exposure mapping	137
8.8.5.2 Coring	137
8.8.5.3 Borehole pressure meter	137
8.8.5.4 Video monitoring	137

9

Hazards, Risks and Environment	143
9.1 Preamble	143
9.1.1 Example of a mine fill risk	143
9.2 Terminology	144
9.3 Risk management	144
9.3.1 Introduction	144
9.3.2 Communication and consultation	144
9.3.3 Establishing the context	145
9.3.4 Risk identification	146
9.3.5 Risk analysis	146
9.3.6 Risk evaluation	147
9.3.7 Risk treatment	149
9.3.8 Monitoring and reviewing	149
9.3.9 Recording the risk management process	150
9.4 Some aspects of implementing risk management	150
9.4.1 Establishing effective risk management	150
9.4.2 Life cycle issues	150
9.4.3 Limitations of risk assessment techniques	151
9.4.4 Common pitfalls with risk assessments	151
9.5 Environmental aspects of mine fill	151
9.5.1 Successful use of mine fill	151
9.5.2 Unsuccessful use of mine fill	152
9.6 Mine fill risk register	152
9.6.1 Preamble	152
9.6.2 Risk register	152
9.7 Suggested reading	154
9.8 Acknowledgement	154

10

Emerging Technologies and Current Research	159
10.1 Preamble	159
10.2 Summary of responses to requests to comment	159
10.3 Review of content of selected papers from MINEFILL 1998, MINEFILL 2001 and MINEFILL 2004	164
10.3.1 MINEFILL 1998	164
10.3.2 MINEFILL 2001	166
10.3.3 MINEFILL 2004	167

Glossary	171
General terms	171
Terms specific to chapter 6: Paste Fill	176
Terms specific to chapter 9: Hazards, Risks and Environment	178