

CONTENTS

	ACKNOWLEDGEMENTS	I
	ABSTRACT	II
	CONTENTS	III
	LIST OF ABBREVIATIONS AND TERMS	VIII
0	EXECUTIVE SUMMARY	1
1	INTRODUCTION	3
	1.1 Aims and limitations	3
	1.2 Project Reports	4
	1.3 Organization of the Thesis	4
2	ALKALI AGGREGATE REACTION - GENERAL	6
	2.1 History	6
	2.2 Mechanism of reactions	9
	2.2.1 Alkali Silica Reaction	9
	2.3 Conditions for AAR in concrete	17
	2.3.1 Alkali reactive minerals and components	17
	2.3.2 Alkalies	19
	2.3.3 Humidity	24
3	AAR RELATED TO NORWEGIAN CONCRETE CONDITION climate, geology and cements	28
	3.1 The climate in Norway	28
	3.2 The geology of Norway	30
	3.2.1 Bedrock	30
	3.2.2 Glaciofluvial deposits	35
	3.2.3 Aggregates	38
	3.3 Norwegian cements	39
4	AAR IN NORWAY-UP TO NOW	45
	4.1 Published investigations	45
	4.2 Remedial measures	48
	4.3 Preventive measures	49
	4.4 SINTEF FCB AAR research project	50
5	FIELD INVESTIGATIONS	51
	5.1 Norwegian dams	51
	5.1.1 Field inspections in the 1920s	52
	5.1.2 Field inspections in the 1960s	53
	5.1.3 Field inspections in the 1990s	54

5.2	Field investigations for AAR in selected geological areas, 1988 and 1989	55
5.3	Regional field investigation carried out in 1990	57
	5.3.1 The field inspection	57
	5.3.2 The data base	59
	5.3.3 The classification system	60
	5.3.4 The map plots	62
	5.3.5 Classification of structures related to geology	64
	5.3.6 Frequency of max. crack width in structural elements	68
	5.3.7 Cracking in structural elements related to environmental exposure	74
5.4	Conclusion	81
6	DIAGNOSIS	83
6.1	Introduction	83
6.2	Structures	84
	6.2.1 Map cracking	84
	6.2.2 Volume expansion	85
	6.2.3 AAR and other deterioration processes	86
	6.2.4 AAR and map cracking	87
6.3	Cores	87
	6.3.1 Reaction rims	88
	6.3.2 White reaction products in voids	89
	6.3.3 Quantification of reaction rims and reaction products in voids	89
6.4	Fluorescence impregnated polished half cores (PS)	91
	6.4.1 The importance of large samples	91
	6.4.2 Dark zonation	93
	6.4.3 Deleterious cracking	94
	6.4.4 Microcracking in aggregates and mortar parts	95
	6.4.5 Relationship between cracked aggregates and cracks in mortarpart in concretes with deleterious AAR	97
	6.4.6 Microcracking related to years of construction	98
6.5	Fluorescence impregnated thin sections (TS)	99
	6.5.1 Sign of the reaction	100
	6.5.2 Reaction products	100
	6.5.3 Reaction types	102
	6.5.4 Classification of deterioration classes	105
	6.5.5 Types and amounts of reaction products in thin section with deleterious AAR	106
	6.5.6 Quantity of reaction products in thin sections with deleterious AAR	107
	6.5.7 Ettringite like precipitations in cracks and airvoids	108
6.6	Dark zonation examined under UV-light and by SEM/EDX	110
6.7	Equivalent water/cement ratio in concretes	112
6.8	Laboratory concretes	112
	6.8.1 Concrete and mortar samples	113
	6.8.2 PS -samples	113
	6.8.3 Thin sections	114
6.9	Hypothesis on the sequential development of AAR in Slow/Late-reactive aggregates - from a petrographic viewpoint	115
6.10	Conclusion	121

7	ALKALI REACTIVE AGGREGATES	124
7.1	Historical review	124
7.2	Methodology to identify alkali reactive aggregates in Norwegian concretes	129
7.3	Alkali reactive Norwegian aggregates	130
7.3.1	Igneous rocks	130
7.3.2	Sedimentary rocks	132
7.3.3	Metamorphic rocks	136
7.4	Distribution of alkali reactive aggregates in Norway	139
7.5	Alkali reactive aggregates in Glacio-Fluvial sediments	145
7.6	Conclusion	146
8	MICROTEXTURE, COMPOSITION AND ALTERATION OF ALKALI REACTIVE ROCKS	148
8.1	Introduction	148
8.2	Grain size	149
8.3	Deformation and recrystallization	158
8.3.1	Cataclasis	158
8.3.2	Strained quartz	159
8.3.3	Subgrain	160
8.3.4	Recrystallization	161
8.3.5	Norwegian reacted aggregates	162
8.4	Minerals	166
8.5	Alterations in reacted Norwegian aggregates	166
8.5.1	Weathering	166
8.5.2	Diagenesis	166
8.5.3	Metamorphism	167
8.5.4	Norwegian reacted aggregates	168
8.6	Conclusion	172
9	LABORATORY TESTS OF AGGREGATES	173
9.1	Introduction	173
9.2	Test material	174
9.3	Not recommended test methods for Norwegian aggregates	176
9.3.1	ASTM C 227 mortar bar method	176
9.3.2	TI-B 51 Danish accelerated mortar bar method	177
9.3.3	Danish chemical shrinkage method - TK 84	178
9.3.4	Japanese Fresh-Con CBRC Rapid Method	180
9.4	Recommended test methods for Norwegian aggregates	181
9.4.1	Canadian concrete prism test CAN3-A23.2-14A	181
9.4.2	South African accelerated mortar bar test NBRI-M185	
9.5	Rate of expansion for Norwegian aggregates by NBRI-M	187
9.6	Limit values of potentially reactive aggregates - by NBRI-M	192
9.7	Petrographic analysis	195
9.8	Recommended test procedure for evaluation of Norwegian aggregates for alkali reactivity - NB 19, November 1991	199
9.9	Conclusion	201

10	REACTION PRODUCTS	203
10.1	Field concrete	203
10.1.1	Visual observations	203
10.1.2	SEM/EDX-analysis	204
10.1.3	XRD - analysis	213
10.1.4	Reaction products heated to 210°C and 800°C	218
10.1.5	Thermal analysis (DTA/DTG-TG)	219
10.1.6	Composition of white reaction products in air voids	221
10.2	Laboratory concretes	222
10.2.1	Visual and microscopic methods	222
10.2.2	SEM/EDX -analysis	223
10.2.3	XRD -analysis	229
10.2.4	Thermal analysis	231
10.2.5	Composition of white reaction products in CAN 3 sample	232
10.3	Conclusion	232
10.3.1	Field concretes	232
10.3.2	Laboratory concretes	234
11	SUMMARIZING RESULTS AND CONCLUSIONS	235
11.1	Field inspections	235
11.2	Diagnosis	235
11.3	Alkali reactive aggregates	236
11.4	Microtexture of reacted aggregates	239
11.5	Laboratory test of aggregates	240
11.6	Reaction products	241
	REFERENCES	245
	APPENDICES I-X	263

Appendices includes the following:

- APPENDIX I: Photos from structures, cores, PS, TS and SEM
- APPENDIX II: Lists of selected investigated structures from a database (with structure number)
- APPENDIX III and IV: Spreadsheet of observations from investigated cores, PS and TS
- APPENDIX V: Spreadsheet of observation in 96 reacted aggregates
- APPENDIX VI: List of reference rock samples and thin sections
- APPENDIX VII: Results from expansion tests
- APPENDIX VIII and IX: Spreadsheet of EDX-analyze results of reaction products from field concretes and



Norsk betong - og tilslagslaboratorium AS, Osloveien 18 B, 7018 Trondheim www.nbt.no
Norwegian Concrete and Aggregate Laboratory Ltd, Osloveien 18 B, 7018 Trondheim Norway

laboratory concretes

APPENDIX X: XRD transcriptions from reaction products