

TABLE OF CONTENTS

	PAGE
ABSTRACT	I
ACKNOWLEDGEMENTS	III
LIST OF ABBREVIATIONS	V
TABLE OF CONTENTS	VI
LIST OF TABLES	XII
LIST OF FIGURES	XIV
CHAPTER 1 INTRODUCTION	1
1.1 FIELD OF STUDY	1
1.2 PURPOSE OF THE STUDY	6
1.3 OUTLINE OF THESIS	8
CHAPTER 2 LITERATURE REVIEW	11
2.1 INTRODUCTION	11
2.2 ALKALI-AGGREGATE REACTIONS (AAR)	11
2.2.1 Alkali-Silica Reaction	12
2.2.2 Alkali-Carbonate Reaction	13
2.3 ESSENTIAL COMPONENTS OF ALKALI-AGGREGATE REACTION	14
2.3.1 Sufficient Alkalis	14
2.3.2 Reactive Constituents	15
2.3.3 Sufficient Moisture	20
2.3.4 Temperature	21
2.4 MECHANISMS OF ALKALI-AGGREGATE REACTIONS	22
2.4.1 Chemistry and Mechanism of Alkali-Silica Reaction	23
2.4.2 Chemistry and Mechanism of Alkali-Carbonate Reaction	29
2.4.2.1 Characteristics of alkali-carbonate reactive aggregate	35
2.5 SYMPTOMS OF AAR AND THEIR IMPACT ON THE ENGINEERING PROPERTIES OF CONCRETE	39
2.5.1 Symptoms of Alkali-Silica Reaction	39
2.5.2 Effect of Alkali-Silica Reaction on the Engineering Properties of Concrete	43
2.5.3 Symptoms of Alkali-Carbonate Reaction	44

2.6	DIFFERENT TEST METHODS USED IN EVALUATING ALKALI-AGGREGATE REACTIONS	46
2.6.1	Petrographic Examination of Aggregate	47
2.6.2	Mortar-bar Expansion Test	48
2.6.3	Accelerated Mortar-bar Expansion Test	49
2.6.4	Quick Chemical Method	50
2.6.5	Concrete Prism Test	50
2.6.6	Rock Cylinder Test	51
2.6.7	Concrete Prism Test for Alkali-Carbonate Reactivity	52
2.6.8	Concrete Micro-Bar Test	52
2.6.9	Tests for Evaluation of Alkali-Aggregate Reactions in Hardened Concrete	53
2.7	MITIGATION MEASURES AGAINST ALKALI-AGGREGATE REACTIONS	55
2.7.1	Mitigation Measures Against Alkali-Silica Reaction	55
2.7.1.1	Limiting moisture	55
2.7.1.2	Using non-reactive aggregate	56
2.7.1.3	Limiting the alkali content of concrete	56
2.7.1.4	Using supplementary cementing materials (SCM)	56
2.7.2	Guidelines for Avoiding ASR in New Structures	60
2.7.3	Mitigation Measure Against Alkali-Carbonate Reaction	61
CHAPTER 3	MATERIALS AND EXPERIMENTAL DETAILS	64
3.1	INTRODUCTION	64
3.2	MATERIALS	64
3.2.1	Aggregate Samples Collection	64
3.2.2	Cement and SCMs	68
3.3	EXPERIMENTAL PROGRAM AND DETAILS	69
3.3.1	Evaluation of Alkali-Reactivity of the Egyptian Aggregate	70
3.3.1.1	Petrographic study	70
3.3.1.2	Standard test methods	71
3.3.2	Concrete mixes containing low-alkali cement, SCMs and chemical admixtures	77
3.3.3	Concrete Microbar and Rock Cylinder Test Mixes	82

3.3.4 Concrete mixes used in structural performance of concrete affected by ACR	82
3.3.5 Mechanism of ACR	83
3.4 TEST TECHNIQUES AND PROCEDURES	85
3.4.1 Petrographic Analysis of Coarse Aggregates	85
3.4.2 Concrete Prism Test (CPT)	86
3.4.3 Accelerated Mortar Bar Test (AMBT)	88
3.4.4 Concrete Micro Bar Test (CMBT)	89
3.4.5 Rock-Cylinder Method for Potential Alkali-Reactivity of the Carbonate Aggregates	90
3.4.6 Determination of Potential Alkali-Carbonate Reactivity by Chemical Composition	91
3.4.7 Compressive Strength	92
3.4.8 Splitting Tensile Strength	93
3.4.9 Pull-Out Test	93
3.4.10 Rapid Chloride Permeability Test	94
3.4.11 Chloride Migration Coefficient from Non-Steady State Migration Experiment	96
3.4.12 Scanning Electron Microscopy (SEM)	99
3.4.13 X-Ray Diffraction (XRD)	100
3.4.14 X-Ray Florescence (XRF)	100
CHAPTER 4 EVALUATION OF ALKALI-REACTIVITY FOR THE EGYPTIAN AGGREGATE	101
4.1 INTRODUCTION	101
4.2 EXPERIMENTAL RESULTS	102
4.2.1 Petrographic Study	102
4.2.2 XRF Test Results	120
4.2.3 XRD Test Results	123
4.2.4 SEM Test Results	129
4.2.5 The Determination of the Potential Alkali-Carbonate Reactivity of Quarried Carbonate Rocks By Chemical Composition (CSA A23.2-26A)	135
4.2.6 Petrographic Number	137
4.2.7 Concrete Prism Test Results	137

<i>Table of Contents</i>	IX
4.2.8 Accelerated Mortar Bar Test Results	139
4.2.9 Concrete Micro-Bar Test Results	140
4.2.10 Rock Prism Test Results	143
4.3 DISCUSSION	144
4.4 CONCLUSIONS	148
 CHAPTER 5 ADOPTING THE CONCRETE MICRO-BAR TEST AND ENHANCING THE ROCK CYLINDER TEST FOR EVALUATION OF THE ALAKLI REACTIVITY OF THE CARBONATE AGGREGATES	 149
5.1 INTRODUCTION	149
5.2 EXPERIMENTAL TEST RESULTS	151
5.2.1 Concrete Microbar Test (CMBT)	151
5.2.1.1 Specimen dimensions, mix proportion, and compaction	151
5.2.1.2 Effect of the aggregate particle size on the expansion in CMBT	152
5.2.1.3 Effect of the alkali soaking solutions on the expansion in CMBT	155
5.2.1.4 Effect of testing period on the expansion in the CMBT	159
5.2.1.5 Effect of testing conditions on the expansion in CMBT	161
5.2.1.6 The efficiency of the CMBT in evaluating SCMs as mitigation measures for the AAR	163
5.2.1.7 The correlation between the different accelerated tests (CMBT, AMBT) and CPT	164
5.2.2 Rock Prism Test	167
5.2.2.1 Sample preparation	167
5.2.2.2 The correlation between the expansion produced from the cylindrical and the prismatic rock samples in the rock cylinder test	172
5.3 DISCUSSION	172
5.4 CONCLUSIONS	174
 CHAPTER 6 STRUCTURAL PERFORMANCE AND PREVENTIVE MEASURES FOR CONCRETE PREPARED FROM ALKALI REACTIVE AGGREGATES	 176

<i>Table of Contents</i>	X
6.1 INTRODUCTION	176
6.2 EXPERIMENTAL TEST RESULTS	185
6.2.1 Impact of ACR-Induced Expansion on Mechanical Properties of Concrete	185
6.2.1.1 Impact of ACR-induced expansion on the compressive strength of concrete	185
6.2.1.2 Impact of ACR-induced expansion on the splitting tensile strength of concrete	189
6.2.1.3 Impact of ACR-induced expansion on the bond strength of concrete	191
6.2.2 Impact of ACR-Induced Expansion on Mass Transport Properties of Concrete	193
6.2.2.1 Impact of ACR-induced expansion of concrete on charges measured in coulombs during RCPT	193
6.2.2.2 Impact of ACR-induced expansion of concrete on Non-Steady State Migration (NSSM) coefficient measured during the rapid migration test	195
6.2.3 Preventive Measures for AAR-Induced Expansion of the Egyptian Aggregates	198
6.2.3.1 Low-alkali cement	198
6.2.3.2 Fly ash	200
6.2.3.3 Sodium monophosphate	206
6.3 DISCUSSION	206
6.3.1 Engineering Properties of Concrete Susceptible to ACR	206
6.3.2 The Use of Low-Alkali Cement and Fly Ash as Mitigation Measures for AAR-Induced Expansions of Egyptian Aggregates	208
6.4 CONCLUSIONS	210
 CHAPTER 7 FACTORS AFFECTING THE MECHANISM AND ALKALI-REACTIVITY OF AGGREGATES	 202
7.1 INTRODUCTION	202
7.2 EXPERIMENTAL TEST RESULTS	203
7.2.1 The Factors Affecting AAR of Egyptian Aggregates	203

<i>Table of Contents</i>	XI
7.2.1.1 Effect of alkali level on the expansion due to ACR	204
7.2.1.2 Effect of temperature on the expansion due to ACR	206
7.2.1.3 Effect of clay minerals content of the rock on the expansion due to ACR	207
7.2.1.4 Effect of regeneration of alkalis	210
7.2.2 The Mechanism of the Alkali-Reactivity of Egyptian Aggregates	212
7.3 DISCUSSION	220
7.4 CONCLUSIONS	222
CHAPTER 8 GENERAL CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDIES	223
8.1 SUMMARY AND GENERAL CONCLUSIONS	223
8.2 RECOMMENDATIONS FOR FURTHER STUDIES	226
REFERENCES	228
APPENDICES	243
ARABIC SUMMARY	261