

# **A STUDY ON HIGH PERFORMANCE CONCRETE USING SANDSTONE AGGREGATES**

**PARAMASIVAM SURESH KUMAR**



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UNIVERSITI MALAYSIA SABAH

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**SCHOOL OF ENGINEERING AND INFORMATION  
TECHNOLOGY  
UNIVERSITI MALAYSIA SABAH  
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OF THE REQUIREMENTS FOR  
THE DEGREE OF DOCTOR OF PHILOSOPHY**

**SCHOOL OF ENGINEERING AND INFORMATION  
TECHNOLOGY  
UNIVERSITI MALAYSIA SABAH  
2006**

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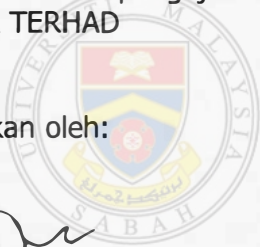
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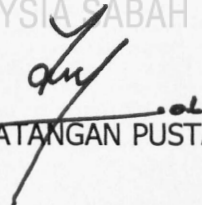
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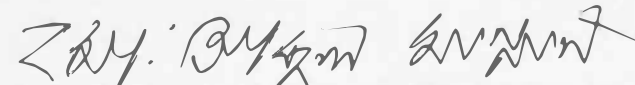


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## DECLARATION

The materials in this thesis are original except for quotations, excerpts, summaries and references, which have been duly acknowledged.



PARAMASIVAM SURESH KUMAR

PS03-008-035 (A)

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## ABSTRACT

An investigation into the potential use of crushed sandstone aggregates in high performance concrete (HPC) has been carried out. A suitable mix design of HPC has been developed using crushed sandstone coarse and fine aggregates. The engineering properties of both fresh and hardened HPC have been obtained by conducting tests on slump, air content, fresh concrete density, compressive strength, flexural strength and modulus of elasticity. The long-term compressive strength performance of HPC has been studied. The flexural behaviour such as ultimate load capacity, deflection and crack width at service load, deflection and curvature ductility, and position of neutral axis have been determined on prototype reinforced HPC beams at two points load. The durability performance of hardened concrete has been conducted by doing the sorptivity, absorption and permeable pore voids, rapid chloride penetration test, chloride diffusion by 90-day salt ponding and, wet and dry cycle. In this investigation three types of curing conditions have been employed to see the effect of curing on strength and durability. The most satisfactory performance in engineering properties on HPC is observed in full water curing. Combination of silica fume and fly ash as partial replacement of cement with crushed sandstone aggregates found to synergistic effects on workability, strength and durability on HPC. This investigation concludes that locally available sandstone aggregates can be used in HPC production. In future, the prospect for resource utilization of marginal quality sandstone aggregates in HPC can be explored further.

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## **ABSTRAK**

### **KAJIAN KE ATAS KONKRIT BERKEKUATAN TINGGI MENGUNAKAN AGREGAT BATU PASIR**

*Satu penyiasatan telah dijalankan ke atas potensi penggunaan agregat batu pasir hancur dalam Konkrit Prestasi Tinggi (HPC). Rekabentuk campuran HPC yang bersesuaian telah dibentuk dengan menggunakan agregat batu pasir hancur kasar dan halus, sifat-sifat kejuruteraan kedua-dua HPC segar dan keras telah diperolehi dengan melakukan ujian ke atas runtuhan, kandungan udara, ketumpatan knokrit segar, kekuatan mampatan, kekuatan lenturan dan modulus keelastikan. Prestasi kekuatan jangka panjang HPC telah dikaji. Sifat kelenturan seperti kapasiti beban akhir, pembengkokan dan keretakan keluasan pada beban servis, pembengkokan dan kemuluran kelengkungan, dan posisi paksi neutral telah ditentukan ke atas protaip rasuk HPC bertetulang pada beban dua titik. Prestasi ketahananlasakan konkrit keras telah dilakukan dengan menjalankan ujian "sorptivity", penyerapan dan liang kosong telap, ujian penusukan klorida cepat, resapan klorida pada 90 hari perendaman garam dan kitar basah dan kering. Dalam penyiasatan ini, tiga jenis keadaan pengawetan telah digunakan untuk melihat kesan pengawetan ke atas kekuatan dan ketahananlasakan. Prestasi yang paling memuaskan dalam sifat kejuruteraan telah diperhatikan pada HPC yang diawetkan dalam pengawetan air sepenuhnya. Kombinasi fume silika dan debu terbang sebagai pengganti separa simen bersama agregat batu pasir hancur didapati mempunyai kesan sinergi ke atas keboleherjaan, kekuatan dan ketahananlasakan ke atas HPC. Penyiasatan ini menyimpulkan bahawa agregat batu pasir hancur tempatan boleh digunakan untuk penghasilan HPC. Pada masa hadapan, prospek penggunaan sumber agregat batu pasir yang berkualiti margin boleh diterokai dengan lebin lanjut dalam HPC.*

# CONTENTS

<b>DECLARATION</b>	ii
<b>ACKNOWLEDGEMENT</b>	iii
<b>ABSTRACT</b>	iv
<b>ABSTRAK</b>	v
<b>CONTENTS</b>	vi
<b>LIST OF TABLES</b>	xii
<b>LIST OF FIGURES</b>	xiv

## **CHAPTER 1: INTRODUCTION - HIGH PERFORMANCE CONCRETE AND AGGREGATES**

1.1.	High Performance Concrete	1
1.2.	Function of Aggregates	2
1.3.	Crushed Stone Sand	2
1.4.	Importance of Study	3
1.5.	Alkali-Silica Reaction	4
1.5.1.	Reactive Aggregate	5
1.5.2.	Petrography of Sandstone Aggregate	6
1.5.3.	Justification of reactive aggregate used in HPC	8
1.6.	Research Objectives	9
1.7.	Scope of Work	10

## **CHAPTER 2: LITERATURE REVIEW OF HPC USING DIFFERENT AGGREGATES**

2.1.	Introduction	12
2.2.	HPC with Classification	12
2.3.	Importance of HPC Mixes	13
2.4.	Aggregate Classification	15
2.5.	Coarse Aggregate Characteristics	16
2.5.1.	Effect of Shape and Texture	17
2.5.2.	Effect of Grading	19
2.5.3.	Effect of Water Absorption	20



2.5.4.	Effect of Mineralogy and Coatings	20
2.5.5.	Effect of Strength and Stiffness	21
2.5.6.	Effect of Maximum Size	22
2.5.7.	Effect of Specific Gravity	22
2.6.	Fine Aggregate Characteristics	23
2.6.1.	Effect of Shape and Texture	24
2.6.2.	Effect of Grading	25
2.6.3.	Effect of Water Absorption	26
2.6.4.	Effect of bulking	26
2.7.	Microfines Characteristics	26
2.7.1.	Effect of Shape and Texture	28
2.8.	Crushed Stone Sand in Concrete	29
2.9.	Properties of Concrete Made with Different Aggregate	32
2.9.1.	Effect on Mechanical Properties of Concrete	32
2.9.2.	Effect on Flexural Behaviour of Reinforced Concrete Beams	33
2.9.3.	Effect on Durability	38
2.10.	Concrete Made with Reactive Aggregate	39
2.10.1.	Effect on Mechanical Properties	39
2.10.2.	Effect on Durability	42
2.10.3.	Control or Reduce the Aggregate Reaction	43
2.11.	Concluding Remarks	44

### **CHAPTER 3: MATERIALS AND TEST METHODS**

3.1.	Introduction	46
3.2.	Materials	46
3.3.	Binders	46
3.3.1.	Cement	47
3.3.2.	Silica Fume	47
3.3.3.	Fly Ash	48
3.4.	Coarse and Fine Aggregate	48
3.4.1.	Sandstone Coarse Aggregate	48
3.4.2.	Fine Aggregate	49
3.4.3.	Influence of Crushed Sandstone Sand on the Properties of Fine Aggregate	51

3.5.	Water	53
3.6.	Superplasticiser	53
3.7.	Reinforcement	54
3.8.	Mixing	54
3.9.	Moulding, Casting and Demoulding	55
3.10.	Curing	55
3.11.	Tests for Fresh Concrete	57
3.12.	Tests for Hardened Concrete Specimens	57
	3.12.1. Compressive Strength	58
	3.12.2. Flexural Strength	58
	3.12.3. Static Modulus of Elasticity	58
	3.12.4. Test for Quality Control of Concrete	59
3.13.	Flexural Test on Prototype Reinforced Concrete Beam	60
	3.13.1. Fabrication of Steel Reinforcement and Strain Gauge Fixation	60
	3.13.2. Formwork Fabrication and Curing of Prototype Reinforced Concrete Beam	63
	3.13.3. Experimental Set Up and Instrumentation	64
3.14.	Durability Test	67
	3.14.1. Sorptivity	68
	3.14.2. Absorption and Permeable Pore Voids	69
	3.14.3. Rapid Chloride Permeability Test	69
	3.14.4. 90-day Salt Ponding Test	71
	3.14.5. Wet and Dry Cycle Test with NaCl Solution	73

#### **CHAPTER 4: MIX DESIGN AND STRENGTH DEVELOPMENT OF HPC**

4.1.	Introduction	75
4.2.	Trial Mix Design of HPC with Crushed Sandstone Aggregates	75
	4.2.1. Arbitrary Mix Design	77
	4.2.2. Mix Design based on Absolute-Volume Method	78
	4.2.3. Acceptable Mix Design	81
4.3.	Fresh Concrete Properties	82
	4.3.1. Slump	82
	4.3.2. Air Content	83

4.3.3.	Fresh Concrete Density	83
4.4.	Consistency Test for Acceptable Mix Design	85
4.5.	Long Term Performance of Compressive Strength under Different Curing	87
4.5.1	Effect of Water Curing (W1)	87
4.5.2	Effect of Air-Dry Curing (W2)	90
4.5.3	Effect of Site Curing (W3)	93
4.6.	Conclusions	96

## **CHAPTER 5: FLEXURAL BEHAVIOUR OF REINFORCED HPC BEAMS**

5.1.	Introduction	98
5.2.	Description of Test Beams	98
5.2.1.	Geometry of Beam Specimens	98
5.2.2.	Reinforcement Details of Beam Specimens	99
5.3.	Basic Mechanical Properties for Analysis	100
5.4.	Ultimate Moments	102
5.5.	Deflection Characteristics	103
5.6.	Crack Behaviour	106
5.6.1.	Crack Width	106
5.6.2.	Crack Spacing and Height	111
5.6.3.	Cracking Moment and Cracking Moment of Inertia	112
5.7.	Ductility Indices	114
5.8.	Strain Distribution	117
5.8.1.	Concrete Strain and Applied Load	119
5.8.2.	Steel Strain and Crack Width	121
5.8.3.	Neutral Axis and Strain	123
5.9.	Conclusions	124

## **CHAPTER 6: DURABILITY PROPERTIES OF HPC**

6.1.	Introduction	126
6.2.	Sorptivity	126
6.3.	Absorption and Permeable Pore Voids	130
6.4.	Rapid Chloride Permeability Test	132
6.5.	90-Day Salt Ponding Test	136
6.5.1.	Diffusivity	140

6.6.	Wet and Dry Cycle test with Salt Solution	141
6.7.	Chloride Penetration Depth	144
6.8.	Conclusions	147

## **CHAPTER 7: CONCLUSIONS AND RECOMENDATIONS**

7.1.	General Remarks	149
7.2.	Concluding Remarks	150
7.3.	Suggestions for Further Investigation	152

## **REFERENCES**

### **APPENDIX A: DETERMINATION OF DURABILITY PROPERTIES OF HPC**

A.1.	Procedure for Determination of Absorption and Permeable Pore Voids	167
A.2.	Determination of Total Charge Passed Using Trapezoidal Equation	168
A.3.	Determination of Chloride Ion Concentration	169
	A.3.1. Spectrophotometer	169
	A.3.2. Sample Preparation	170
	A.3.3. Filter Analysis	171

### **APPENDIX B: ARBITRARY TRIAL MIXES OF HPC**

### **APPENDIX C: EXPRESSIONS USED FOR ANALYSIS OF REINFORCED HPC BEAMS**

C.1.	Expressions for Ultimate Moment Calculation	173
	C.1.1. British Standards (BS 8110:2002)	173
	C.1.2. American Concrete Institute (ACI 318:2002)	174
C.2.	Expressions for Deflection Characteristics	174
	C.2.1. As per BS 8110	174
	C.2.2. As per ACI 318	175
C.3.	Expressions for Crack Characteristics	175
	C.3.1. Cracking Moment	175
	C.3.2. Cracked Moment Of Inertia	176
	C.3.3. Crack width as per BS 8110	177

**APPENDIX D : EXPRESSIONS USED FOR DETERMINATION OF  
DIFFUSIVITY**

D.1. Determination of the Apparent Diffusivity of Chloride  
Ion Penetration

179

**LIST OF PUBLICATIONS DERIVED FROM THIS STUDY**

180



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## LIST OF TABLES

Table 1.1:	Investigation Approach and Performance of HPC	11
Table 2.1:	Classification of HPC	12
Table 2.2:	Properties of Stones as Aggregate	18
Table 2.3:	Basic Properties of Different Fine Aggregate	23
Table 2.4:	Microfines Limits in Different Countries	28
Table 2.5:	Basic Mechanical Properties of HPC	32
Table 2.6:	Selected Durability Properties of HPC	39
Table 3.1:	Chemical Composition and Physical Properties of OPC, SF and FA	47
Table 3.2:	Physical Properties of Sandstone Coarse Aggregate	49
Table 3.3:	Chemical Composition of Sandstone Aggregate	49
Table 3.4:	Physical Properties of Fine Aggregate	50
Table 3.5:	Mix Proportion of River Sand and Crushed Sandstone Sand	50
Table 3.6:	Properties of Combined Fine Aggregates	53
Table 3.7:	Curing Conditions for the Test Specimens	57
Table 3.8:	Standard Deviation and Coefficient of Variation For Different Types of Controls	60
Table 4.1:	Trial Mix Proportions Based On Absolute-Volume Method	80
Table 4.2:	Fresh and Hardened Concrete Properties	81
Table 4.3:	Acceptable Mix Proportion and Properties of Concrete	84
Table 4.4:	Standard Deviation for 28-Day Compressive Strength Of Water Cured Concrete	86
Table 5.1:	Reinforcement Details of Prototype Beams	100
Table 5.2:	Mechanical Properties of Companion Concrete	101
Table 5.3:	Experimental and Predicted Ultimate Moment for the Tested Beams	102
Table 5.4:	Deflection Characteristics for the Tested Beams	104
Table 5.5:	Comparison of Crack Width at Service Loads	107
Table 5.6:	Characteristics of Crack Spacing and Crack Height	112
Table 5.7:	Experimental and Predicted Cracking Moment and Cracking Moment of Inertia	113
Table 5.8:	Ductility and End Rotations for the Tested Beams	115
Table 5.9:	$x/d$ ratio and Strain Values for the Tested Beams	123

Table 6.1:	Sorptivity Test Results	129
Table 6.2:	Absorption and Permeable Pore Voids	132
Table 6.3:	Chloride Ion Penetrability in Concrete As Per ASTM C 1202	135
Table 6.4:	Diffusivity Test Results	141
Table 6.5:	Chloride Penetration Depth for Different Test	144
Table B.1:	Arbitrary Mix Proportions and Properties of Concrete	172



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## LIST OF FIGURES

Figure 1.1:	Forms of Silica and Their Reactivity	6
Figure 1.2:	Photomicroscope Image of Sandstone Aggregate	7
Figure 3.1:	Samples of river sand and crushed sandstone sand	50
Figure 3.2:	Grading curve of the fine aggregate for different mixes	51
Figure 3.3:	Reinforcement Cages for Beams	61
Figure 3.4:	Grinded Surface to Fix Strain Gauge	61
Figure 3.5:	Strain Gauge on the Smoothened Surface	62
Figure 3.6:	Strain Gauge Connected with Electrical Wires	62
Figure 3.7:	Strain Gauges Covered with Silicone Gel	62
Figure 3.8:	Fabricated Wooden Form Work for the Prototype Test Beam	63
Figure 3.9:	Typical Curing of the Beams with Wet Hessian	63
Figure 3.10:	Typical Loading Arrangements for Prototype Reinforced Concrete Beam Test	66
Figure 3.11:	Position of Electrical Strain Gauges and Demec Studs	66
Figure 3.12:	Curvaturemeter	67
Figure 3.13:	Hand Held Microscope for Crack Measurement	67
Figure 3.14:	Sorptivity Test	68
Figure 3.15:	Test Set-up for the RCPT	70
Figure 3.16:	Electrical Configuration of RCPT Apparatus	70
Figure 3.17:	Test Samples Employed For Vacuum Saturation	71
Figure 3.18:	Test Samples Coated at Surface with Epoxy Paste	71
Figure 3.19:	The Specimens Being Poned into NaCl Solution	73
Figure 3.20:	Specimens Immersed in NaCl Solution (Wet condition)	74
Figure 3.21:	Specimens Dried in Laboratory (Dry condition)	74
Figure 4.1:	Compressive Strength Development of Different mixes Under W1 Curing	88
Figure 4.2:	Reactive Rim Surrounding Sandstone aggregates Under W1 for (a) Mix C; (b) Mix CS and (c) Mix CSF	90
Figure 4.3:	Compressive Strength Development of Different Mixes Under W2 Curing	91
Figure 4.4:	Reactive Rim Surrounding Sandstone aggregates Under W2 for (a) Mix C; (b) Mix CS and (c) Mix CSF	93



Figure 4.5:	Compressive Strength Developments of Different Mixes Under W3 Curing	94
Figure 4.6:	Reactive Rim Surrounding Sandstone aggregates Under W3 for (a) Mix C; (b) Mix CS and (c) Mix CSF	96
Figure 5.1:	Typical Reinforcement Arrangements and Geometry of the Test Beam	99
Figure 5.2:	Normalised Load ( $P_a/P_u$ ) Versus Mid Span Deflection For Tensile Steel Ratio (a) 1.34 %; (b) 2.10 % and (c) 3.24 %	105
Figure 5.3:	Load Vs Crack Widths for Beam Types C1, C2 & C3 ; ( b) CS1, CS2 & CS3 and (c) CSF1, CSF2 & CSF3	109
Figure 5.4:	Relationship between crack width and concrete strain for Tensile Steel ratio (a) 1.34 %; (b) 2.10 % and (c) 3.24 %	110
Figure 5.5:	Moment - Curvature Relation for Beams (a) C1, C2 & C3 ; ( b) CS1, CS2 & CS3 and (c) CSF1, CSF2 & CSF3	116
Figure 5.6:	Moment and Strain Distributions for the Beams (a) C1, C2 & C3 ;( b) CS1, CS2 & CS3; (c) CSF1, CSF2 & CSF3	118
Figure 5.7:	Applied Loads and Concrete Compression Strains of Different Beams (a) C1, C2 & C3 ;( b) CS1, CS2 & CS3 and (c) CSF1, CSF2 & CSF3	120
Figure 5.8:	Relationship between Crack Width and Steel Strain of different Beams (a) C1, C2 & C3 ;( b) CS1, CS2 & CS3 and (c) CSF1, CSF2 & CSF3	122
Figure 6.1:	Typical Plot of Sorptivity Data (Mix CS, 90 Days)	129
Figure 6.2:	RCPT Results for Three Curing Conditions (a) Mix C; (b) Mix CS and (c) Mix CSF	136
Figure 6.3:	Chloride Concentration at Different Depths under 90-Day Salt Ponding for (a) Mix C; (b) Mix CS and (c) Mix CS	139
Figure 6.4:	Chloride Concentration under Wet and Dry Cycle For (a) Mix C; (b) Mix CS and (c) Mix CSF	143
Figure 6.5:	Typical Formation of White-Purple Precipitation on Concrete for (a) 90-Salt Ponding; (b) Wet and Dry Cycle and (c) RCPT	146
Figure A.1:	DR 2010 Hach, Spectrophotometer	169
Figure A.2:	Powder Samples Being Filtered	170
Figure C.1:	Cross Section and Stress Block of Beam	173

# CHAPTER 1

## INTRODUCTION-HIGH PERFORMANCE CONCRETE AND AGGREGATES

### 1.1. High Performance Concrete

High performance Concrete (HPC) is known as a high technology construction material, proving to be very cost effective, reliable, and having long term durability in natural environment. The study of HPC has been an extremely active research area in recent years. The definition of HPC is based on establishing value of workability, strength and durability. Broadly speaking, HPC is defined as "concrete made with appropriate materials combined according to a selected mix design and properly mixed, transported, placed, consolidated, and cured so that the resulting concrete will give excellent performance in the structure in which it will be exposed, and with the loads to which it will be subjected for its design life" (Forster, 1994a).

With the development of HPC, the strength and durability of concrete has improved largely. Although HPC offers many advantages, due to the restriction of the manufacturing process and the availability of quality raw materials, the development of HPC is still limited.

In high-rise buildings and bridges, the stiffness of the structure is of interest to structural engineers. On certain projects the minimum modulus of elasticity has been specified as a means of increasing the stiffness of the structure. The modulus of elasticity is affected significantly by the properties of aggregates and mix proportion (Balbakki et al., 1991). The highest possible of modulus can be obtained

through the use of good quality coarse and fine aggregate from the same source (Kosmatka *et. al.*, 2002).

According to Neville (1997), the aggregate with low modulus of elasticity is more beneficial with respect to HPC. There is a growing interest in substituting alternative materials in concrete and HPC. Hence, the innovative technological developments in the field of waste materials derived from industrial by-products have increased to improve the HPC properties.

### **1.2. Function of Aggregates**

Aggregates both coarse and fine are considered to be inert fillers for concrete to reduce the amount of cement required. The characteristics of aggregate play the substantial role in the fresh and hardened properties of concrete as it occupies about 50 to 80% of total concrete volume. It is commonly accepted that the properties of aggregates used in HPC have great influence on the mechanical properties and durability (Aitcin, 2003). In general, the coarse aggregate used in HPC should be hard, dense, non-reactive and durable. The fine aggregate should be free from organic impurities, clay or silt and relatively coarser sand with fineness modulus in the range 2.5 -3.2 is recommended (Nawy, 2001). A higher degree of fine and coarse aggregate packing requires less water and thus increasing the concrete quality.

### **1.3. Crushed Stone Sand**

Due to depletion of river sand in the use of concrete and environmental pressure on solid waste disposal, the use of crushed stone sand, commonly known as quarry dust (solid waste) is considered a viable alternative to river sand in concrete. Crushed

stone sand is a fine material formed during the process of conversion of rock into aggregate and has particle size ranging from 4 mm to dust size ( $< 0.075$  mm). The crushed stone sand is a material of high quality. The fine particles and irregular shape of the crushed stone sand has harsh effects on the workability and finishability of concrete. These harsh effects have given crushed stone sand a poor reputation in the construction industry. However, recent studies have shown that this crushed stone sand can be used to produce concrete with higher compressive and flexural strengths (Bonavetti *et. al.*, 1994, Celik *et. al.*, 1996).

The crushed stone sand based on its quality, can replace 15 to 60 % of total fine aggregate in concrete (Mannan *et. al.*, 2001, Mulu *et. al.*, 2003). The use of crushed stone sand is desirable from the social and environmental view point. It also needs to be economically and technically viable.

#### **1.4. Importance of Study**

Due to the increased level of construction in Malaysia in the forthcoming years, it is expected that fine aggregate suitable for use in concrete will become scarce or not economical to produce. As sources of quality concrete aggregate become depleted, the use of more marginal aggregates will mean an increased use of reactive aggregates in concrete.

In Sabah, Malaysia, the average annual production of stone aggregates including river pebbles is about 12 million tonnes. Crushed sandstone aggregate is about 6.5 million tonnes of total aggregates, which is more than 54 %. During the crushing process at the quarry, about 22 % of the particle has the size 3 mm to dust

which is known as crushed sandstone sand (Hisam *et. al.*, 2002). Sandstone sand consists of about 85% sand sized material and 15 % of silt and clay.

In places where there is a scarcity of suitable materials for HPC the economic considerations may necessitate experimenting with suitable locally occurring substitute materials. But some aggregates can cause detrimental effect on durability performance of the concrete. Sandstone is a reactive material, which has detrimental effect on concrete durability. One of the major concerns with such aggregate is the alkali-silica reaction. This has raised the concern now when the concrete industry is forced to develop durable concrete with local available sources.

### **1.5. Alkali-Silica Reaction**

Alkali-silica reaction (ASR) occurs either in mortar or concrete. ASR is a deleterious chemical reaction between hydroxyl ( $\text{OH}^-$ ) ions associated with alkalis (sodium and potassium) present in cement or other sources and certain reactive siliceous components that may present in aggregates, producing the gel. When this alkali-silica gel absorbs moisture, it expands, and eventually produces cracks in aggregate particles as well as in the cement paste in concrete (Prezzi *et. al.*, 1997). It causes serviceability problem in concrete structures. The following three conditions must be satisfied for expansive ASR to occur:

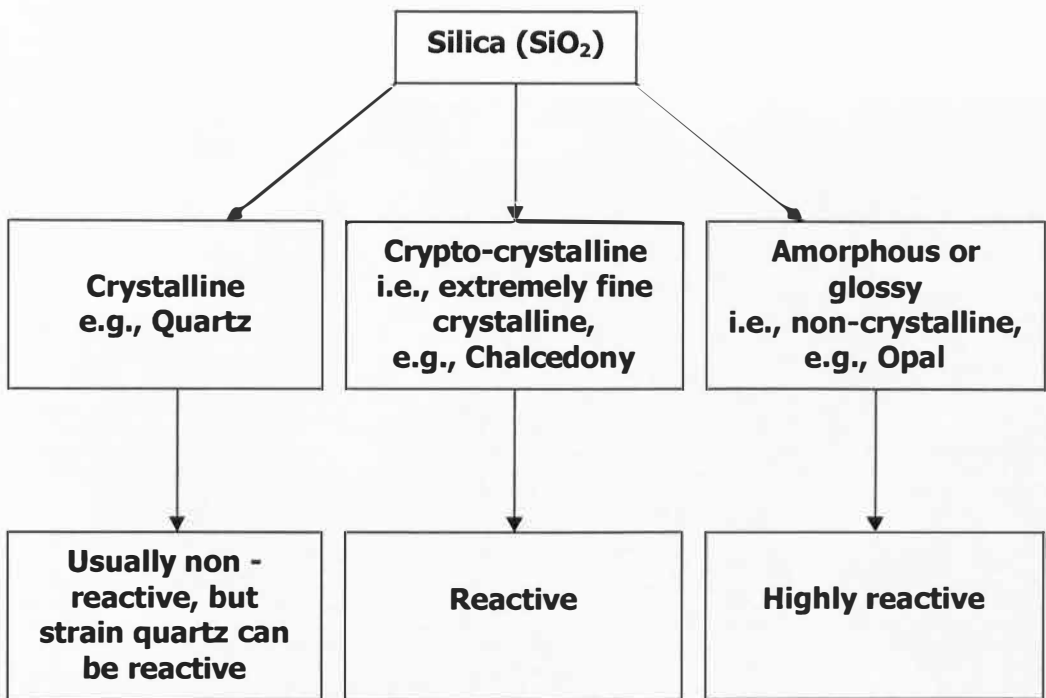
1. A reactive form of silica or silicate must be present in the aggregate.
2. Sufficient alkali, sodium (Na) and/or potassium (K), mainly from cement, must be available.
3. Sufficient moisture, i.e., not less than 80% relative humidity (RH) in the pore structure of the concrete or mortar, is required.

### 1.5.1. Reactive Aggregate

It is the form of silica that determines whether a siliceous aggregate is reactive or not. Many of the coarse aggregates used in construction are siliceous in composition, i.e., high in silica ( $\text{SiO}_2$ ) content. However, they are not necessarily reactive. Certain reactive aggregates do not exhibit maximum expansion unless the aggregate is present in critical range.

The proportion of reactive aggregate particles that produces maximum expansion for a given alkali content and water-binder ratio (w/b) in concrete is known as the pessimum proportion. For example, 3% opal (reactive mineral) in aggregate shows maximum expansion. With parameters such as alkali content, w/b, etc. being constant, the difference in expansion of different potentially reactive aggregates mainly depends on (i) inherent reactivity of their constituent mineral phases or rock types, (ii) grain size of the reactive particle, and (iii) proportion of these reactive phases within the reactive aggregate.

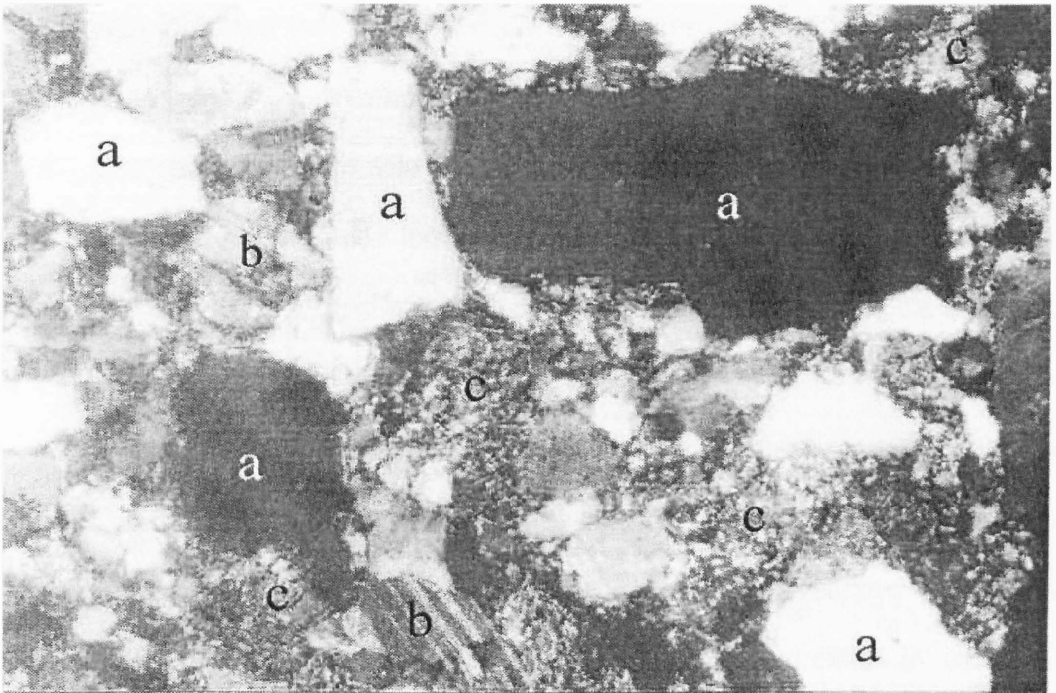
Not all aggregates that are susceptible to ASR, however, show the pessimum effect. Aggregates without this pessimum effect exhibit increasing expansion as a function of the amount of reactive particles present in the aggregate. Fine aggregate is more susceptible to ASR because of its higher surface area. Figure 1.1 shows the different forms of silica and their reactivity



**Figure 1.1: Forms of Silica and Their Reactivity**

### 1.5.2. Petrography of Sandstone Aggregate

Petrography is a comparatively quick way to predict aggregate reactivity based on microscopic examination of aggregate samples. Mineral properties in aggregate determine aggregate reactivity. Photomicroscope image of sandstone aggregate is shown in Figure 1.2. A petrographical, mineralogical and textural description of the different sources of Kota Kinabalu quarried sandstone aggregate has the following characteristics (Felix, 1989). Thin-section studies showed that the sandstone consisted of 70 % quartz, 8 % chert, 15 % feldspar and less than 10 % rock fragments including sedimentary, metamorphic and igneous rock. The chemical compositions of sandstone aggregate are shown in Table 3.3, Chapter 3. It contains mainly silica 82 % and aluminum 9 % and all other compositions are marginal. The sandstones are poorly sorted, that is, grain of various sizes occurred together (0.03 to 3 mm). The frame work is dominated by quartz grains which are generally rounded to subrounded.



a - Silica; b - Feldspar; c - Rock fragments (Chert, igneous and metamorphic rock)

### **Figure 1.2: Photomicroscope Image of Sandstone Aggregate**

The interstitial matrix consists of silt-sized quartz, mica, and probably also sub-microscopic clay minerals at grain interfaces. Internal porosity of sandstone is clearly enhanced adjacent to mica. In general, the sandstone is held together by phyllosilicate minerals (clay and altered rock fragments) due to local compaction and rarely by chemical cement, and it is relatively soft and friable. Coarser granularity and better crystallinity suggest that sandstone is less liable to silica dissolution. For the case of late or slow alkali-silica reaction with sandstones contains stained quartz and metamorphosed sediments such as phyllite, causes swelling of aggregate particles. This is the most common form of ASR, and there is a lack of literature on reactive mechanism, considered still under investigation.