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Civil Engineering (Construction Management)

Mitigation of cement Alkali Silica Reactivity in Hydropower Concrete Structures - A case Study Merowe Dam and Upper Atbara Dam Projects.

تقليل تفاعل القلويات والسليكات في خرسانة منشآت الطاقة الكهرومائية -دراسة حالة لمشروعي سد مروي ومجمع سد أعالي عطبرة.

Research in Partial Fulfillment of the Requirements for the Degree of M.Sc.

In Civil Engineering Construction Management

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January 2023

Abstract:

The research focuses on the mitigation of cement alkalis and siliceous of aggregates reactivity (ASR) influence in hydropower concrete structures and takes Merowe Dam Project (MDP) and Dam Complex of Upper Atbara Project (DCUAP) as case study.

The research aims to find out methodology, for mitigating alkali silica reaction that may occur in hydropower concrete structures and to compare, the laboratory testing results obtained, with the international standard requirements for compliance.

The results of the cement material; OPC and GGBS used in both projects, Merowe Dam Project (MDP) and Dam Complex of Upper Atbara (DCUAP), were of low level alkali content, less than 0.6% of Na_2O equivalent. The results of crushed and natural aggregates; combined with moderate and high levels of alkali content cement for expansion test, were of low level reactive aggregates. Based on the laboratory testing results obtained from petrographic examination, chemical tests, mortar bar tests and accelerated mortar bar tests concerning alkali silica reaction for fine and coarse aggregates used in concrete and mortar production for construction of MDP & DCUAP projects, all the results fulfilled and verified the standard requirements and limits stated for mitigating alkali content in the cement material and the siliceous found in the aggregates materials, therefore, the concrete and mortar produced from such materials were mitigated from deleterious expansion and damage due to alkali silica reaction. Using of supplementary cementitious material (SCM) Fly Ash to replace 25% of the Cement used in concrete mixes not only for minimizing risk of any probable Alkali-Silica Reactivity mitigation reason, but also for reducing heat of hydration, as a filler to reduce seepage, to increase workability of concrete and as a benefit by reducing the cost of concrete production. It is obvious, from the testing results obtained; to mitigate alkali silica reactivity; there are two options: combine innocuous aggregate with even high level alkali content cement will fulfill the standard requirements for mitigating ASR or combine reactive natural sand with low level alkali content, also will mitigate ASR.

The recommendations of this research for future study had been stated as to: establish visual inspection system for existing concrete structures of dams, bridges, water tanks and similar concrete structures which were exposed to wetting environment, establish service record for aggregates quarries which have been used in concrete production for dams, bridges and similar concrete constructed from the same aggregate quarries and further study of local natural pozzolan from Buyda desert central volcanic field.

المستخلص

ركز البحث على تقليل أثر تفاعل قلويات الأسمنت وسليكات الحصى في المنشآت الخرسانية المائية للطاقة و أخذ دراسة حالة لمشروع سد مروى ومشروع مجمع سدى أعالى عطبرة وستيت.
الغرض من هذا البحث هو منهج لتقليل تفاعل القلويات والسليكات التي قد تحدث في خرسانات المنشآت المائية ومقارنة النتائج المختبرية المتحصل عليها مع متطلبات المقياس العالمى للتطابق.
نتائج مادة الأسمنت البورتلاندى العادى وأسمنت الخبث المستخدمة فى سد مروي وسدي أعالي عطبرة وستيت كانتا من مواد الأسمنت ذات مستوى القلويات المنخفضة أقل من 0.6% مكافئ أكسيد الصوديوم. نتائج مادة الحصي المكسور والحصي الطبيعي المخلوط مع مادة أسمنت ذات مستوي قلويات معتدلة وقلويات عالية لإختبار التمدد, كانت ذات مستوى تفاعل منخفض وبناءا علي النتائج المختبرية المتحصل عليها من إختبار التحليل الصخري والإختبار الكيميائي وإختبار تمدد قضبان العجينة الأسمنتية وإختبار تمدد قضبان العجينة الأسمنتية المستعجل ذات الصلة بتفاعل القلويات والسليكات للحصي الناعم والحصي الخشن المستخدم في منتجات الخرسانة والعجينة الأسمنتية, لتشييد سد مروي وسدي أعالي عطبرة وستيت فإن كل النتائج قد إستوفت وحققت متطلبات حدود المقياس العالمي الموضوع لتقليل تفاعل القلويات في الأسمنت والسليكات الموجودة في مادة الحصي. وعليه فان الخرسانة والعجينة الأسمنتية المنتجة من تلك المواد تكون محمية من التمدد والتلف والتدهور بسبب تفاعل القلويات والسليكات. إستخدام الرماد المتطاير بنسبة.ظهرت النتائج ان 25% إحلال للأسمنت بالرماد المتطاير في الخلطة الخرسانية, ليس فقط لتقليل أي خطر محتمل من تفاعل القلويات والسليكات ولكن أيضا لتقليل حرارة الإماهة, مادة مالئة لتقليل التسرب, زيادة تشغيل الخرسانة وكذلك تفيد في تقليل تكلفة إنتاج الخرسانة. وضح من نتائج الإختبارات المتحصل عليها, لتقليل تفاعل القلويات والسليكات, هناك خياران إثنان: خلط حصي غير نشط مع أسمنت ذا مستوي عالي من القلويات, سوف يحقق المتطلبات القياسية لتقليل تفاعل القلويات والسليكات أو خلط حصي طبيعي نشط مع أسمنت ذا مستوي منخفض أيضا يقلل من تفاعل القلويات والسليكات.
توصيات هذا البحث تتمثل في: إنشاء نظام تفتيش نظري للمنشآت الخرسانية المائية الموجودة في السودان والكباري وخزانات المياه الخرسانية وكل المنشآت الخرسانية المشابه والتي تتعرض لبيئة رطبة. إنشاء سجل خدمة لمحاجر الحصي التي أستخدمت في تشييد خرسانات الخزانات والكباري والمنشآت الخرسانية المشابه. دراسة إضافية للبوزلانا المحلي في صحراء بيوضة.

Dedication

To souls of my parents, to my lovely two wives; Amna and Laila and to my daughters, the three flowers; Dr. Hadya, Engineer Hajer and the medicine student Zain Alsharaf.

Acknowledgments

I would like to thank all the people who helped me along the way to complete this research. First of all, I am deeply indebted to my supervisor, Dr. Mashair Abdelrahim Mohammed, for her fully support and advice. I would also like to thank the General Director of Dams Implementation Unit (DIU), Mr. Mohammed Nouradeen, who kindly allowed for me to use the laboratory testing results documents from MDP and DCUAP. I must thank my friends and colleagues in Lahmeyer International and DIU the supervision staff who provided me consider support.

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Symbols & Abbreviations:

ASR = Alkali Silica Reaction
AAR = Alkali Aggregate Reaction.
ACR = Alkali Carbonate Reaction.
MDP = Merowe Dam Project.
UDQ: Umm Duweima Quarry.
DCUAP = Dam Complex of Upper Atbara Project.
NS = Natural Sand.
CS = Crushed Sand.
ECC = Egyptian Company Cement.
GYC = Guangxi Yufeng Cement.
SCM = Supplementary Cementitious Material.
PCCP = Portland Cement Concrete Pavements.
Na_2O = Sodium Oxide.
Na_2Oe = Sodium Oxide equivalent.
K_2O = Potassium Oxide.
HO^- = Hydroxide.
NaOH =Sodium hydroxide
$LiNO_3$ = Lithium Nitrate.
Li_2CO_3 = Lithium Carbonate.
LiOH = Lithium Hydroxide
ACI =American Concrete Institute.
ASTM = American Society for Testing and Materials.
EN = Europaische Norm (European Standard)
FNS = Ferronickel Slag.
AMBT = Accelerated Mortar Bar Test.
TGA = Thermogravimetric Analysis.
C-S-H = Calcium Silicate Hydrates (Pozzolanic).
CaO/SiO_2 = Calcium oxide Silicon dioxide ratio.
CO_2 = Carbone dioxide.
XRD = X-Ray Diffraction

CHAPTER ONE

INTRODUCTION

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INTRODUCTION

1.1Introduction

Concrete is one of the most widely used construction materials. It has excellent properties, such as durability and low cost material compared to other construction materials and it is made up of basic ingredients such as a cement, aggregate, water and may add some additives or admixtures to improve properties when fresh or hard. Meanwhile, durability of concrete is degraded by various chemical reactions such as carbonation, chemical erosion, alkali-silica reaction (ASR). This process usually affected the materials used to make concrete. In particular, it is well known that aggregates play an important role in the ASR. Alkali-silica reactivity requires water to initiate the reaction.

ASR is a detrimental reaction between the metastable amorphous silica from aggregates and the alkaline pore solution of the cement matrix (Poole, 1992; ajabipour et al., 2015), and normally occurs inside the concrete. Due to the internal attribute and irreversibility of the induced degradation, ASR is commonly referred to as “concrete cancer” (Subasi et al., 2010; Swamy and Al-Asali, 1988). Cracking due to alkali aggregate reaction generally becomes visible when concrete is 5 to 10 years old. The mechanisms of ASR induced deterioration consist of the dissolution of the silica in metastable forms in the alkaline pore solutions, formation and gelation of ASR gel by cross-linking and coagulating, and volume swelling of ASR gel in the presence of moisture, which generates internal pressure leading to expansion and cracking of the concrete (Bérubé et al., 2002; Davraz and Gündüz, 2008; Glasser, 1992; Powers and Steinour, 1955).

The reaction can be visualized as a two-step process:

- Alkali hydroxide+reactive silica gel → reaction product (alkali-silica gel appendix B-11)
- Gel reaction product+moisture → expansion.

Therefore, the occurrence of ASR damage of concrete needs three essential prerequisites: presence of amorphous silica in metastable forms of aggregates, high alkalinity of the concrete pore solution and sufficient moisture (Chatterji et al., 1989). Water is an essential for the 'carrier' of alkali cations and hydroxyl ions. Water is absorbed by the gel which is the essential element in developing pressures to crack the concrete. Sufficient moisture is necessary to induce pressure on gels. These gels are formed by the alkali-silica reaction that leads to expansion and cracking of the aggregate in surrounding paste, loss in mechanical properties of concrete and eventually damages the structures.

Concrete mixtures involved in highly reactive aggregates and high-alkali cements have exposed little or no expansion in a dry environment. Likewise, the concrete structure with a large amount of local moisture typically results in more expansion.

The sodium and potassium alkalis found in cement originate from the raw materials used for the manufactures of Portland cement. These alkalis are released during normal hydration. The pore fluid present in Portland cement concrete is a mixture of calcium, sodium and potassium hydroxides. Most of the calcium hydroxide produced during hydration is present as a crystalline hydroxide but most of the sodium and potassium are present in the pore solution and are primarily responsible for high alkalinity (El-Tilib, cited in Hobbs,1988). Because in general, Portland cement is usually the first to be accused of contributing alkali to the concrete mix, the reaction is normally assumed to be a reaction between disordered silica and the sodium and potassium alkalis released by a high alkali Portland cement. Cement plants produce a variety of cement types using basically two processes: The wet process is being phased out because of its high energy requirement and is being replaced by the dry process. However, the energy-efficient process and stricter air pollution laws generate a kiln dust that is high in alkalis.

The kiln dust is a disposal problem that can be minimized by recycling. The end result is higher alkali cement. The total alkali content of Portland cement is, according to ASTM C150, the sum of sodium oxide and potassium oxide expressed as equivalent sodium oxide (Na_2O+ 0.658K_2O).

There are two ways in mitigation of Alkali – Silica Reactivity (ASR) aggregates evaluation:

1- Laboratory Methods:

Many test methods for evaluating the potential for deleterious expansion due to alkali reactivity of an aggregate have been proposed and some have been adopted as ASTM standards. However, there is no general agreement on the relation between the results of these tests and the amount of expansion to be expected or tolerated in service. Therefore, evaluation of the suitability of an aggregate should be based upon judgment, interpretation of test data, and results of examinations of concrete structures containing the same aggregates and similar cementitious materials having similar levels of alkalis.

The mortar bar test method covers the determination of the susceptibility of cement-aggregate combinations to expansive reactions involving hydroxyl ions associated with the alkalis (sodium and potassium) by measurement of the increase in length of mortar bars containing the combination during storage under prescribed conditions of test. Alkalis participating in the expansive reactions usually are derived from the cement; under some circumstances they may be derived from other constituents of the concrete or from external sources. Two types of alkali reactivity of aggregates are recognized:

(1) an alkali-silica reaction involving certain siliceous rocks, minerals, and natural or artificial glasses and

(2) an alkali-carbonate reaction involving dolomite in certain calcitic dolomites and dolomitic lime stones. The method is not recommended as a means to detect the latter reaction because expansions produced in the mortar bar test by the alkali-carbonate reaction are generally much less than those produced by the alkali-silica reaction for combinations having equally harmful effects in service.

Data correlating the results of tests performed using this test method with performance of cement-aggregate combinations in concrete in service, results of petrographic examination of aggregates, and results of tests for potential reactivity of aggregates by chemical methods have been published in Test Method C 289 and should be consulted in connection with the use of results of tests performed using this test method as the basis for conclusions and recommendations concerning the use of cement-aggregate combinations in concrete.

2 - Service Record Evaluation:

Comparable concrete service record data, if available, should take precedence over laboratory test results in most cases. To be considered valid, a record of satisfactory service should be available for at least 10 years for aggregates, cementitious materials, and exposures sufficiently similar to those in which an aggregate is being considered for future use. Longer periods of documented service may be required for proposed work designed for a particularly long service life in moist conditions, or if laboratory test results show that the aggregate may be deleteriously reactive.

Mitigation of Alkali-Aggregate Reaction: If an aggregate has been judged to be potentially deleteriously reactive in concrete either through laboratory or service record evaluation, use of the aggregate should be considered with measures known to prevent excessive expansion due to alkali-aggregate reaction.

1.2 Problem statement

Alkalis in the pore water of concrete plus reactive silica components of aggregates in the presence of water will produce gel like products, the products will expand and damage the concrete. ASR has long been a major durability problem in concrete containing reactive aggregates with the hydroxyl ions of the concrete pore solution.

The research problem stated as: how to minimize, mitigate and prevent the effects of ASR deleterious in MDP and DCUAP hydropower concrete structures.

1.3 Objectives

1.3.1 General Objectives:

1. To study and document the problems of concrete using in special structures like dams.
2. To understand the fundamentals sources and methods of mitigation ASR in hydropower concrete structures.
3. To be aware of the factors that contribute to reaction and expansion of ASR.
4. To put the strategies and methods of testing for preventing expansions due to ASR.
5. To develop and enhance proper application of the techniques available today to new dam’s concrete construction.

1.3.2 Special Objectives:

1. To determine the various level of alkali contents of the cements used in MDP and DCUAP.
2. To record and justify the aggregates used in MDP and DCUAP, are innocuous or reactive.
3. To determine suitable dosage as percentage of SCM fly ash to replace cement for mitigating ASR.

4. To identify the types of cement and aggregates to be used in concrete dams.

1.4 Research methodology

As a methodology, this research is adopting as experimental work. The research will initially collect the data, graphs and charts related to the study from Hydropower Concrete Structures – Merowe Dam and Dam Complex of Upper Atbara Projects, and compare the findings to the stated limits of the technical specifications of the projects and International Standards Requirements.

The laboratory assessing and evaluating tests, were carried out on concrete materials, namely; the aggregates and the cement which were used in the construction of MDP & DCUAP. The tests were performed in accordance to ASTM C 295 petrographic examination, ASTM C 289 chemical test, ASTM C 227 expansion mortar bar test and ASTM C 1260 expansion accelerated mortar bar test.

1.5 Research Structure:

Chapter One: Introduction

Chapter Two: Literature Review and Previous Studies

Chapter Three: Materials and testing

Chapter Four: Results and Discussion

Chapter Five: Conclusion and Recommendations.

CHAPTER TWO

LITERATURE REVIEWAND PREVIOUS STUDIES

CHAPTER TWO

LITERATURE REVIEW AND PREVIOUS STUDIES

2.1 INTRODUCTION

The chapter consists of the literature review background as a history of the alkali silica reactivity (ASR) due to the problems facing concrete structures, when first time discovered and the international standards adopted for testing the aggregates. The chapter also contains the previous studies of researchers worldwide and their obtained results.

Concrete can be damaged by a chemical reaction between active silica constituents of the aggregate and alkalis in the cement, this process is known as alkali silica reaction. The reactive forms of silica occur in several types of rocks as stated (Neville, Brooks, 2010)

The definition of the alkali silica reactivity(ASR), alkali aggregate reactivity(AAR) and alkali carbonate reactivity(ACR) in accordance to American Concrete Institute(ACI) can be defined as follows:

2.1.1 Alkali Aggregate Reaction, AAR:

Chemical reaction in either concrete or mortar between hydroxyl ions (OH^-) of the alkalis (sodium and potassium) from hydraulic cement or other sources, and certain constituents of some aggregates; under certain conditions deleterious expansion of concrete or mortar may result.

2.1.2 Alkali Carbonate Reaction, ACR:

Chemical reaction in either concrete or mortar between hydroxyl ions (OH^-) of the alkalis (sodium and potassium) from hydraulic cement or other sources, and certain carbonate rocks, particularly calciticdolostone and dolomite limestone, present in some aggregates. The reaction is usually accompanied by dedolomitization and expansion of the affected aggregate particles, leading to abnormal expansion and cracking of concrete in service.

2.1.3 Alkali-Silica Reaction, ASR:

Chemical reaction in either concrete or mortar between hydroxyl ions (OH^-) of the alkalis (sodium and potassium) from hydraulic cement or other sources, and certain siliceous rocks and minerals, such as opal, chert, microcrystalline quartz, and acidic volcanic glass, present in some aggregates. This reaction and the development of the alkali-silica gel reaction product can, under certain circumstances, lead to abnormal expansion and cracking of the concrete.

ASR is far more widespread than ACR. However, it should be noted that some test methods used to detect alkali-silica reactive aggregates may fail to detect alkali-carbonate reactive aggregates. In addition, measures used to prevent damaging ASR are generally ineffective in preventing ACR expansion and, consequently, alkali-carbonate reactive rocks should not be used in the production of concrete.

2.2 History of AAR:

Problems due to ASR were first identified in the State of California in the 1930s and reported by Thomas Stanton of the California State Division of Highways in 1940 (Stanton, 1940), appendix B-1 photo. Stanton's studies demonstrated that the expansion of mortar bars was influenced by the alkali content of the cement, the type and amount of the reactive silica in the aggregate, the availability of moisture, and temperature. He further showed that expansion was negligible when the alkali content of the cement was below 0.60% Na_2Oe and that expansion could be reduced by pozzolans, thus setting the groundwork for preventive measures. Subsequent to Stanton's discovery, ASR was diagnosed as the cause of abnormal cracking in a number of dams operated by the U.S. Bureau of Reclamation, such as the Parker Dam in Arizona (Meissner, 1941) and in the 1940s a number of agencies initiated studies on ASR in the USA (Army Corps of Engineers, Bureau of Public Roads, Portland Cement Association) and other countries (Denmark and Australia). ASR is now recognized as a major cause of concrete deterioration, incidences having occurred in most, if not all, of the numerous countries worldwide.

Alkali carbonate reaction (ACR) was first discovered by Swenson as the cause of concrete deterioration in Canada at about the same time that ASR was first documented in the same country (Swenson, 1957). ACR was subsequently implicated in cases of degradation of concrete structures in the USA (Hadley 1961) and alleged cases of ACR have occurred in Virginia, West Virginia, Kentucky, Missouri, Tennessee, Iowa, Illinois, Indiana, and New York, as well as England, Bahrain, Iraq, and China (Ozol, 2006). However, unlike ASR, problems with ACR are still restricted to a few isolated locations worldwide. Consequently, there has been comparatively little research conducted on this topic. A series of international conferences on Alkali-Aggregate Reaction (ICAAR) in concrete began in1974 (see Table 2.1). The first conference was held in Denmark in 1974 with 23 delegates presenting 13 papers and representing just 5 countries (Denmark, Germany, Iceland, U.K., USA). Interest in AAR grew rapidly from this time and in 1992 over 300 delegates representing 29 countries attended the 9th ICAAR in London, U.K., and 150 papers were published in the proceedings. Interest has remained at this level since that time with the most recent conference being held in Austin, Texas, USA, in 2012, 131 papers from 27 countries (Thomas et al.,2013).

Table 2.1. International Conferences on Alkali-Aggregate Reaction in Concrete (Thomas et al.,2013).

#	Year	Place	#	Year	Place	#	Year	Place
1	1974	Denmark	6	1983	Denmark	11	2000	Canada
2	1975	Ice Land	7	1986	Canada	12	2004	China
3	1976	U.K.	8	1989	Japan	13	2008	Norway
4	1978	USA	9	1992	U.K.	14	2012	USA
5	1981	South Africa	10	1996	Australia			

Alkali-silica reaction is now widely recognized as one of the more prevalent deterioration mechanisms affecting concrete worldwide.

2.3 Fundamentals Sources and mitigation measures of ASR:

2.3.1 Fundamentals Sources of ASR:

As described in the definition, alkali-silica reaction is a reaction between the alkali hydroxides in the pore solution of concrete (or mortar) and certain types of silica minerals present in some aggregates. The reaction product, an alkali-silica gel with varying amounts of calcium, is hygroscopic having a tendency to absorb water and swell. Under certain conditions the reaction causes expansion of the concrete and may eventually lead to cracking. It is clear from this brief description of ASR that there are three requirements for damaging reaction to occur; (Thomas et al.,2013). these are:

. A sufficient quantity of reactive silica (within aggregates).

. A sufficient concentration of alkali (primarily from Portland cement) and.

. Sufficient moisture.

While Portland cement is considered the main contributor of alkalis, under certain conditions other materials may provide additional alkalis that are available to the reaction. The source of alkalis can be from any of the following:

. Portland cement

. Supplementary cementing materials (e.g., fly ash, slag, silica fume, natural pozzolans)

. Aggregates

. Chemical admixtures

. External sources (e.g., seawater and deicing salts)

. Wash water (if used)

The quantity of alkalis in Portland cement is typically expressed in terms of equivalent sodium (written either Na_2Oe or Na_2Oeq) which may be calculated using the following formula:

$$Na_2Oe = Na_2O + 0.658 * K_2O \tag{2.1}$$

where:

Na_2O and K_2O are the mass percentages of sodium oxide and potassium oxide in the Portland cement as reported on the cement mill test report. The percentage of alkalis in Portland cement is in the range of 0.2 to 1.3% Na_2Oe for most North American sources, but may be as high as 1.65% Na_2Oe or more worldwide.

American Standard for Testing Materials (ASTM) C150 Standard Specification for Portland Cement stated that, Optional Chemical Requirements Equivalent Alkalis (Na_2O + $0.658K_2O$), max, % 0.60 as low-alkali cement. Specify this limit when the cement is to be used in concrete with aggregates that are potentially reactive and no other provisions have been made to protect the concrete from deleteriously reactive aggregates.

Expansion potential is a function of the reactivity of the aggregate and of the total quantity of reactive alkalis available per cubic meter of concrete. The safe level for the content of reactive alkalis available in the concrete must be determined experimentally for each combination of aggregate and cementitious materials. It is obvious that the alkalinity of the pore fluid in the concrete is controlled both by the alkali level of the cement and by the amount of cement in the concrete. When alkali sources other than cement are absent, the reactive alkalis available in a Portland cement concrete (Murari, 2008) are normally calculated by:

$$A = C * a/100 \tag{2.2}$$

Where;

A = alkali content of concrete (kg/m^3)

C = Portland cement content of concrete (kg/m^3)

a = acid-soluble alkali content of Portland cement expressed as a percentage by weight of Na_2O equiv.

In fact, any calculation relating to the reactive alkali content of the concrete should consider the variation of both the cement content in concrete and the alkali content in cement. Therefore, the British Guidance Notes published by the British Concrete Society on minimizing the risk of damage to concrete by alkali-silica reaction recommend" C " as the target mean Portland cement content of concrete and that" a " be the certified average alkali content of Portland cement.

According to the Guidance Notes, " a " can be expressed in the following different ways:

- Acid-soluble alkali content (the average of the last 25 determinations carried out on daily samples prepared in accordance with the British Standards).
- Acid-soluble alkali content which shall not be exceeded (the value of acid-soluble alkali which the cement manufacturers declare will not be exceeded without prior notice).
- Certified maximum acid-soluble alkali content (the value of acid-soluble alkali content which shall not be exceeded for any cement delivery).

Proper allowance also has to be made for alkalis introduced into the concrete by sources other than cement. Alkalis may come from the aggregate, from admixtures, and from brackish water if used as mixing water. The aggregates can be responsible either because of alkali salt contamination or through soluble alkalis release, but the latter event is considered infrequent. Some safe levels of alkali content of concrete in places are summarized below:

Table 2.2 levels of Alkali Content (Murari, 2008):

Countries	Type of mineral	Alkali content
United Kingdom	Reactive aggregates	less than 4 kg/m^3
United Kingdom	Aggregates containing opaline silica	Safe level of 3 kg/m^3
New Zealand	Reactive aggregates	3.5 kg/m^3
USSR, Japanese Industrial Standard, Iranian Standard	Reactive aggregates	3 kg/m^3.

ASTM C 33 Specification for information on potential reactivity of aggregates. Many test methods for evaluating the potential for deleterious expansion due to alkali reactivity of an aggregate have been proposed and some have been adopted as ASTM standards. However, there is no general agreement on the relation between the results of these tests and the amount of expansion to be expected or tolerated in service. Therefore, evaluation of the suitability of an aggregate should be based upon judgment, interpretation of test data, and results of examinations of concrete structures containing the same aggregates and similar cementitious materials having similar levels of alkalis. Results of the tests may assist in making the evaluation. When interpreting expansion of laboratory specimens, consideration should be given not only to expansion values at specific ages, but also to the shape of the expansion curve, which may indicate whether the expansion is leveling off or continuing at a constant or accelerating rate. Valid, comparable concrete service record data, if available, should take precedence over laboratory test results in most cases. To be considered valid, a record of satisfactory service should be available for at least 10 years for aggregates, cementitious materials, and exposures sufficiently similar to those in which an aggregate is being considered for future use. Longer periods of documented service may be required for proposed work designed for a particularly long service life in moist conditions, or if laboratory test results show that the aggregate may be deleteriously reactive. If an aggregate has been judged to be potentially deleteriously reactive in concrete either through laboratory or service record evaluation, use of the aggregate should be considered with measures known to prevent excessive expansion due to alkali aggregate reaction.

2.3.2 Tests for Reactive Aggregates:

Stanton (1940) was not only the first to discover ASR in field structures, but he was also the first researcher to develop a test method to assess aggregate reactivity, and he used this technique to also evaluate the use of pozzolans to control ASR-induced expansion. The method developed by Stanton, which is essentially the same as the current ASTM C 227 test method, is still in use today by some researchers and practitioners, but a wide variety of test methods have been developed and implemented since the time of Stanton's pivotal research on ASR. Some of these test methods have been successful, some have proven to be complete failures, and others fall somewhere in the middle. Through research and development, as well as trial and error, test methods have evolved over the years, and there has been a general convergence in terms of the tests that are generally used.

With regard to alkali-silica reaction (ASR), several tests are used throughout the world to assess the alkali reactivity of aggregates as stated by:(Murari, 2008) These are:

Table 2.3 Standard Test Method (Murari, 2008)

#	Standard Test Method
1	ASTM C 227: "Standard Test Method for Potential Alkali Reactivity of Cement Aggregate Combinations (Mortar-Bar Method)" ASTM C 289: " Standard Test Method for Potential Alkali-Silica Reactivity of Aggregates (Chemical Method)"
2	The ASTM C 295: "Standard Test Method for Petrographic Examination of Aggregate"
3	ASTM C 586: "Standard Test Method for Potential Alkali Reactivity of Carbonate Rocks for Concrete Aggregates (Rock Cylinder Method)"
4	ASTM C 342: "Standard Test Method for Volume Change Potential of Cement Aggregate Combinations"
5	ASTM C 441-05: "Standard Test Method for Effectiveness of Pozzolans or Ground Blast-Furnace Slag in Preventing Excessive Expansion of Concrete Due to the Alkali Silica Reaction"
6	ASTM C 856: "Standard Practice for Petrographic Examination of Hardened Concrete"
7	ASTM C 1105: "Standard Test Method for Length Change of Concrete Due to Alkali Carbonate Rock Reaction"
8	ASTM C 1293: "Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction" ASTM C 1260: "Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)"
9	ASTM C 1567: "Standard Test Method for Determining the Potential alkali-silica reactivity of combinations of cementitious materials and aggregate (accelerated mortar bar method)"
10	AASHTO T 303: "Accelerated Potential Alkali Reactivity of Aggregates (Mortar Bar Method)"
11	AASHTO T 299: "Rapid Identification of Alkali-Silica Reaction Products in Concrete (Also appended to ASTM C 856)"
12	BS 812-123: "Testing Aggregates- Method for Determination of Alkali-silica Reactivity (Concrete Prism Method)"
13	CSA A23.2-25A: "Test Method for Detection of Alkali Silica Reactive Aggregate by Accelerated Expansion of Mortar Bars"
14	BIS 2386 Part-VII: "Methods of Test for Aggregates for Concrete : Alkali Aggregate Reactivity a) Determination of Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar Bar Method); b) Determination of Potential Reactivity of Aggregates (Chemical Method)"
15	BIS 2386 Part-VIII: "Methods of Test for Aggregates for Concrete : Petrographic analysis"
16	Korean Standards, NE Concrete Prism Test.

Minerals, rocks and other substances which are potentially deleteriously reactive with alkalis in cement, Opal, Chalcedony, Tridymite, Cristobalite, Cryptocrystalline, microcrystalline or glassy quartz. Coarse-grained quartz which is intensely fractured, granulated and strained internally or filled with submicroscopic inclusions of which illite is one of the most common. Silicic, intermediate and basic volcanic glasses. Vein quartz.

Table 2.4 Rocks and their Reaction Components (Murari, 2008)

Rocks	**Reactive component**
Igneous rocks:	
Granites , Granodiorites , Charnockites	More than 30 percent strained quartz as characterised by an. undulatory extinction angle of 25° or more.
Pumice, Rhyolites, Andesites, Dacites, Latites, Perlites, Obsidians, Volcanic tuffs	Silicic to intermediate silica rich volcanic glasses; devitrified glass; tridymite.
Basalts	Chalcedony; cristobalite; palagonite; basic volcanic glass.
Metamorphic rocks:	**Reactive component**
Gneisses, Schists	More than 30 percent strained quartz as characterised by an undulatory extinction angle of 250 or more.
Quartzites	Strained quartz as above; 5 percent or more chert.
Hornfelses, Phillites, Argillites	Strained quartz as above; micros crystalline to cryptocrystalline quartz.
Sedimentary rocks:	**Reactive component**
Sandstones	Strained quartz as above; 5 percent or more chert; opal.
Greywackes	Strained quartz as above; microcrystalline to cryptocrystalline quartz.
Siltstones Shales	Strained quartz as above; microcrystalline to cryptocrystalline quartz; opal.
Tillite	Strained quartz as above; microcrystalline to cryptocrystalline quartz.
Chert Flint	Cryptocrystalline quartz; chalcedony; opal.
Diatomite	Opal; cryptocrystalline quartz.
Argillaceous dolomitic limestones Argillaceous calcitic dolostones Quartz-bearing argillaceous calcitic dolostones	Dolomite; phyllosilicates exposed by dedolomitisation .

2.3.3 Mitigation Measures of ASR

A - Preventing and mitigating ASR for new Concrete Structures:

Because repair and rehabilitation of concrete hydraulic structures is costly primarily in relation to emptying the reservoir and interrupting operation. ASR should be primarily prevented and mitigated for a new hydraulic structure. Repair and rehabilitation may only be regarded as "the solution of last resort" for existing structures for which proper precautions were not taken during construction.

Measures to prevent and mitigate ASR involve eliminating one of the three prerequisites and/or changing the nature of the reaction by introducing admixtures. Because it is difficult to fully avoid the water ingress into mass concrete due to the nature of hydraulic structures, efforts are focused on the other two aspects.

A.1 Limiting the alkali content in concrete:

Because a link has been found between the use of Portland cement with alkali content greater than 0.6 percent Na_2O equivalent in concrete and a more severe incidence of ASR, cement with less than 0.6 percent alkali content should be used if available. For potentially reactive aggregates, a maximum alkali content of 0.4 percent in cement is recommended. However, by itself, this is not an absolutely reliable method to control ASR, and other measures should also be taken. The maximum limit of 0.6% Na_2O equivalent in cement was the result of a study initiated in 1940 (Hill 1996). In 1945 Blanks and Meissner determined that 0.5% in cement is much safer limit. Several other research studies performed between 1941 and 1963, namely by Bryant Mather in1952, all concluded that cement with alkali contents lower than 0.60% have shown every little to no ASR damaging effects (Hill, 1996). The most commonly used mitigation method is to control the alkali content in the concrete for the purpose of reducing the hydroxyl ion concentration and eventually the pH of the concrete. Cement is the major source of alkali in the concrete, chemical admixtures, aggregates, and external sources such as deicing salts and seawater. Controlling the alkali content of the cement has been proven to decrease the expansions caused by ASR. A proposed limit of 0.60% has been recommended for the alkali content of cement to be used in concrete to reduce ASR expansions (ACI 221, 1998).

A.2 Using non-reactive aggregate:

Using a non-reactive aggregate and avoiding reactive aggregates will prevent ASR damage (ACI 221,1998). This may be aggregate that has historically performed well or aggregate shown to be non-reactive by tests. However, it is difficult to demonstrate the historical performance because the noticeable ASR deterioration may occur 15 years or more after construction. It should be noted that non-reactive aggregate frequently is not available for many hydraulic structures from the economical point of view.

A.3 Adding pozzolans or slags to concrete:

Research indicates and practice has confirmed that adding ground granulated blast furnace slag and pozzolanic materials (raw or calcined natural pozzolans, fly ash, rice husk ash, silica fume, and metakaolin) to the concrete mix can suppress and mitigate ASR. These materials, having a high content of reactive silica and low levels of calcium and alkali, tend to be efficient in controlling ASR. They may be named as mitigative materials. The mechanism by which a pozzolanic material or slag inhibits the potential ASR distress is well-documented. The effects of a pozzolan or slag will depend on the particular material, reactivity of the aggregate, and alkali content of the Portland cement.

In general, testing should verify the effectiveness of the pozzolan or slag in reducing the expansion potential. As a rule of thumb, the minimum replacement of 25 percent cement with Class F fly ash or Class N pozzolan should be used, while the minimum replacement of 30 percent cement with ground granulated blast furnace slag could be recommended. For example, limestone aggregate is being used to produce the roller-compacted concrete for GomalZam Dam in Pakistan. Tests, according to ASTM C1260, showed that expansion of the concrete specimen without using pozzolan at 16 days was 0.262 percent, indicating potentially deleterious expansion. However, when 30 percent of the Portland cement was replaced with fly ash, expansion at 16 days was reduced to 0.088 percent, indicating innocuous behavior. Similarly, if 40 percent of the cement was replaced with ground granulated blast furnace slag, expansion of the concrete specimen at 16 days was reduced to below 0.1 percent.

A.4 Limiting moisture:

The alkali-silica reaction will not take place in a concrete structure if the internal relative humidity of the concrete is lower than 80%. As a result, keeping the concrete dry will prevent the reaction from occurring. However, a low water cement ratio results in higher cement content, higher alkali content, and a reduced pore space which could lead to higher expansions lowering the permeability of concrete using mineral admixtures is a more viable approach to reducing the deleterious effects of ASR (ACI 221, 1998). Applying a protective coating to concrete is a good solution provided that the coating is correctly installed. Because of the high cost of concrete coatings, this method has been used on a limited basis.

A.5 Mineral admixtures:

Effective mineral admixtures (ACI 221, 1998) include fly ash, silica fume, ground granulated slag, and calcined clay. Mineral admixtures reduce ASR expansions by one or more of the following mechanisms:

- Reducing the alkali content of the concrete mix
- Reducing the pH of the pore solution
- Consuming the calcium hydroxide, which might result in lower swelling.
- Reducing concrete permeability.

A.6 Chemical admixtures:

Lithium salts have been used to prevent excessive ASR expansions. Several salts have been tried, some of which have been shown to be effective. The best results were obtained using lithium nitrate ($LiNO_3$) because:

1) it is non-toxic.

2) Mineral amounts were found significantly reduce the ASR expansions (ACI 221, 1998).

Using lithium compounds: As an electrochemical method, lithium compounds, especially lithium nitrate ($LiNO_3$), can be added to the concrete mix to counter and mitigate ASR. However, special precaution should be taken, because lithium hydroxide (LiOH) and lithium carbonate (Li_2CO_3) have been found to increase the expansion of alkali-carbonate reactive aggregate. Further, some lithium compounds, in insufficient quantities, can actually increase the expansion. This is known as the pessimism effect: At a certain lithium level the concrete will expand significantly, whereas at other levels expansion may be negligible. The lithium nitrate does not exhibit a pessimism effect. Although lithium compounds have been used to mitigate ASR expansion in some structural concrete, research is needed to evaluate the effect on mass concrete.

ASR can be controlled using certain supplementary cementitious materials, in proper proportion, silica fume, fly ash, and ground granulated blast furnace slag. Several natural pozzolans such as calcined clay has also been reported effective in mitigation the ASR effects. Effective mitigation methods need to be available for use with aggregates that are prone to ASR. In order to reduce the cost of construction it is important that reactive aggregate sources be used as effectively as possible.

B - Visual Signs and Remedying of ASR damage in existing structures:

Three conditions are necessary to initiate and sustain AAR in concrete:

(1) Reactive mineral forms must be present in the aggregate materials,

(2) The concentration of alkali hydroxides ([Na+, K+-OH-]) in the concrete pore fluid must be high, and

(3) Sufficient moisture must be present. Concrete elements affected by AAR respond quite differently from one another, reflecting wide variations in the above conditions.

Common visual signs of ASR consist of:

. Cracking

. Expansion causing deformation, relative movement, and displacement

. Localized crushing of concrete

. Extrusion of joint (sealant) material

. Surface pop-out sand surface discoloration and gel exudations

Prior to any remedies, the structural effects of ASR should be thoroughly investigated to determine the extent of ASR deterioration and necessity of repair, as well as repair techniques. The hydraulic structures should be rehabilitated, provided that stability or serviceability is of direct concern. In some severe cases, the dam may be completely replaced, as was the case at Maentwrog Dam in the United Kingdom, or a new spillway may be constructed, as at Chambon Dam in France. Due to the complexity of the hydraulic structures and the extent and nature of ASR, remedial programs for an existing hydraulic structure must be individually established.

The measures explained below are extracted from repair and rehabilitation of several concrete hydraulic structures. Most remedial measures fall into short-term solutions, because the ASR problem cannot be defined in the long term and it is difficult to predict the ultimate, maximum value of expansion.

B.1 Lowering the pool level:

If dam stability is compromised, lowering the reservoir water level may be considered the first step to ensure dam stability before any remedial work begins. This is regarded as a temporary measure.

B.2 Installing anchors:

Vertical anchors may be installed in dams to enhance the shear capacity of the horizontal lift joints. This measure is suitable for dams where the horizontal lift joints are weakened due to ASR effect. In addition, horizontal and inclined anchors can be installed in piers and powerhouses. At Hiwassee Dam in the United States, 140 seven-wire-strand tendons post-tensioned to stress levels between 25 and 35 percent of the ultimate load were installed.

B.3 Cutting slots:

Diamond wire saw cutting is frequently used at dams affected by ASR to release excessive stresses and restore clearances. Thin slots of 10 to 15 millimeters may be cut through the dam, spillway, intake, or powerhouse. If the ASR expansion continues, the saw cutting may be repeated. For instance, at Mactaquac Generating Station in Canada, diamond wire saws have been used to cut slots in the spillway, power intake, and powerhouse in 1988, 1989, 1992, and 1995, as well as to re-cut some slots in 1999 and 2000. In the powerhouse, slots were cut between each of the six units, with the objective of relieving the effects of the distortions caused by longitudinal movements/thrust, and seven longitudinal slots were cut. This is a continuing operation, with cuts made on a yearly basis.

B.4 Grouting the concrete:

To control ASR-induced leakage, grouting the mass concrete may be considered. In several dams, grouting has been performed with cement grout for cracks wider than 0.5 millimeter and with chemical agents for smaller cracks. Practice demonstrates that grouting can alleviate the leakage but cannot stop the ASR process.

B.5 Installing a membrane:

Covering the dam with a geomembrane can be used to prevent water ingress into concrete and to control leakage. At Pracana Dam in Portugal, a 2.5-millimeter-thick polyvinyl chloride (PVC) membrane and a 1.5-millimeter-thick geotextile were placed on the upstream face to provide waterproofing. Similar to grouting, this measure can effectively alleviate the leakage but cannot fully stop the ASR process.

B.6 Treating concrete surfaces:

In some cases, concrete surfaces are treated, including removing calcite formation of concrete surfaces to a depth of 3 to 5 centimeters into sound concrete and then applying reinforced concrete or epoxy grout or similar coatings. The surface treatments can caulk cracks and help protect embedded reinforcement and reinstate the integrity of the cracked concrete. However, it will not significantly retard the rate of reaction and expansion. New cracks will inevitably form as the reaction continues.

2.3.4 Consequences of ASR:

. Loss of concrete strength

. Concrete more permeable

. Reduced capacity

. Reduced service life

. Very costly to rectify

2.4 ASR Today:

More than ninety years after ASR was first documented, much is now known about the chemistry of the reaction, the factors that contribute to the reaction and expansion, methods for testing aggregates, and strategies for preventing expansion. Proper application of the knowledge available today to new concrete construction should result in a very low risk of damage due to ASR occurring in the normal service life of the structure. A number of specifications or practices have been developed in recent years to assist the practitioner in the selection of materials and preventive measures for ensuring durable construction (with regards to ASR).It is well established that the ASR results from a reaction between the alkali hydroxides provided (mainly) by the Portland cement and certain types of reactive silica minerals present in some aggregates, and that limiting the availability of one (or both) of these is an effective means of preventing deleterious expansion due to ASR(Thomas et al. 2012). Thus, selecting “non-deleteriously reactive” aggregates or using “low-alkali cement” have become common practices for preventing ASR, although it is now considered that controlling the alkali content of the concrete is more appropriate than merely limiting the alkali content of the cement. The potential for using pozzolans to control damaging ASR was demonstrated by Stanton (1940) in his landmark paper that first revealed the phenomenon of alkali-silica reaction to the concrete community. The use of pozzolans for this purpose was first put into practice in the same decade when calcined clay was used to prevent ASR in the Davis Dam, which was constructed between 1942 and 1950, the reaction having been implicated as the cause of cracking in the Parker Dam (Meissner 1941), which was completed shortly before construction began on the Davis Dam and is located 88 *miles* (141 *km*) upstream on the Colorado River. Ten years after Stanton’s (1940) discovery of ASR the potential for using fly ash and slag for controlling expansion was first documented, and it is now widely accepted that supplementary cementing materials (SCM) are an effective means for controlling ASR expansion provided they are used at a sufficient level of replacement. The long-term field performance of fly ash in the role of ASR prevention was recently documented (Thomas et al. 2012) in the form of the excellent condition of the 50-year-old Nant-y-Moch Dam in Wales, appendix B-2 photo and the 40-year-old Lower Notch Dam in Canada, both structures being built with the combination of fly ash and highly reactive aggregates. Test methods for correctly identifying reactive aggregates and evaluating the efficacy of preventive measures have constantly evolved since Stanton’s (1940) mortar-bar test, which was a precursor to the standard ASTM C 227 method. There are few options available for mitigating ongoing ASR in existing structures. In other words, once concrete has alkali-aggregate reaction, it is very difficult to stop the reaction. In some cases, it may be possible reduce the availability of moisture and slow the reaction down. In other cases, methods have been developed to either physically confine the expansion or create space to allow for expansion and relieve stresses. Methodologies for evaluating existing concrete structures to (a) determine the extent of ASR and its impact on the concrete, (b) predict the future growth of the concrete due to ASR, and (c) select appropriate strategies for mitigating the effects of ASR. There is comparatively little information on ACR, and consensus has yet to be reached on the exact mechanisms of expansion. Although it is agreed that alkali-carbonate reactive dolomitic limestones have a characteristic texture and composition and undergo a chemical reaction resulting in dedolomitization (dolomite → brucite + calcite), there is disagreement as to whether the accompanying expansion results from this reaction or from reaction of cryptocrystalline silica in the limestone (i.e., ACR expansion may be due to ASR). There does appear to be consensus that, regardless of the true mechanism of expansion, there are features of the alkali-carbonate reaction that set it apart from ASR with aggregates that are undisputedly alkali-silica reaction. These features include (a) the relatively short timeframe before damage is observed, (b) reaction (and expansion) at very low alkali levels, (c) the general ineffectiveness of pozzolans and slag in controlling expansion, and (d) the inability of certain tests to identify the reactive aggregates.

2.5 Previous studies of ASR Mitigation:

2.5.1 Potential ASR of Sudanese Aggregates:

Nour-Allah El-Tilib, carried out a survey on Sudanese aggregates for their alkali-silica reactivity and reported that alkali-silica reaction has been found in some aggregates. (El-Tilib, 1992) collected types of rock samples (granitic, volcanic, sedimentary and recent deposits) from many areas in Sudan: River Nile, Red Sea, Blue Nile and Northern State. His recommendations in all of studies were very useful; they were considered and used in Merowe Dam Project.

Remedial treatment for damage due to ASR may be very costly, and the reaction can cause serious problems of serviceability when it does occur. So it is important to minimize the risk by all means necessary to avoid ASR from the very beginning that is from the initial choice of the aggregate (the easiest way) and the cement.

Nour-Allah study is essentially an empirical investigation and evaluation of Sudanese aggregates using various conventional, rapid and accelerated standard methods (petro graphic, chemical and expansion tests) for detecting the alkali aggregate susceptibility and determining how far an aggregate may be harmfully reactive with alkali in mortars on concretes.

2.5.2 Mitigation of ASR by fly ash (KE Hanna, 2009).

Throughout the state of Nebraska, Portland cement concrete pavements (PCCP) use Platte River sand and gravel exclusively as a fine aggregate. It has been well established that this aggregate is a reactive aggregate that can potentially lead to alkali-silica reaction (ASR). Fly ash has been used as an economic and effective way for ASR mitigation. However, Class C fly ash produced by Nebraska power plants has been identified as a major contributor to the premature deterioration of PCCP. The paper presents the experimental work performed to assess the effect of using Class C fly ash in PCCP to control ASR. The ASTM C 1567 test method was adopted to evaluate the expansion in 16 different mixes that contain different proportions of Class C fly ash, Class F fly ash, slag, and cement. Four mixes have been chosen for overall performance testing based on the ASTM C 1567 test results and material cost. These mixes, which contain at least 15% Class C fly ash in addition to Class F fly ash and/or slag, showed better performance over the current standard mix.

2.5.3 Comparison of ASR Mitigation Methodologies (Islam, Akhtar, 2013):

This study evaluates the dosages of Class F fly ash, lithium nitrate and their combinations to suppress the excessive expansion caused by alkali-silica reactivity (ASR). In order to serve the proposed objective, the mortar bar specimens were prepared from (1) four dosages of Class F fly ash, such as 15, 20, 25 and 30 % as a partial replacement of Portland cement, (2) up to six dosages of lithium nitrate, such as lithium-to-alkali molar ratios of 0.59, 0.74, 0.89, 1.04, 1.19 and 1.33, and (3) the combination of lithium salt (lithium-to-alkali molar ratio of 0.74) and two dosages of Class F fly ash (15 and 20 % as a partial replacement of Portland cement). Percent contribution to ASR-induced expansion due to the fly ash or lithium content, test duration and their interaction was also evaluated. The results showed that the ASR-induced expansion decreased with an increase in the admixtures in the mortar bar. However, the specimens made with the both Class F fly ash and lithium salt produced more effective mitigation approach when compared to those prepared with fly ash or lithium salt alone. The ASR-induced expansions of fly ash or lithium bearing mortar bars by the proposed models generated a good correlation with those obtained by the experimental procedures.

2.5.4 Mitigation by fly ash ASTM C 1567:

(Shafaatian, 2012) stated, ASTM C1567 is a commonly used accelerated test method to determine the required dosage of supplementary cementitious materials (SCMs) to mitigate alkali-silica reaction (ASR) in mixtures containing reactive siliceous aggregates. Past research suggested that fly ash and other SCMs inhibit ASR, primarily through alkali dilution and binding. In ASTM C1567, however, the alkalinity of the pore solution is largely influenced by the penetration of NaOH from the external soak solution; and this could erase the beneficial effects of alkali dilution and binding.

To better understand why fly ash inhibits ASR in this test, the present study performs a quantitative evaluation of six potential ASR mitigation mechanisms:

1- alkali dilution

2- alkali binding

3- mass transport reduction

4- increasing tensile strength

5- altering ASR gel, and

6-reducing aggregate dissolution rate.

The results suggest that (2), (3), (4), and (6) are the primary mitigation mechanisms, while (1) and (5) show a negligible impact.

2.5.5 Mitigation by 25% fly ash:

By **(**Bill Palmer,) There are a few ways to deal with, or mitigate, the potential for ASR, but the most common and affordable way is with fly ash. Tanner has data showing that 25% cement replacement with even very reactive aggregate can completely eliminate expansion. Fly ash mitigates ASR by binding with some of the alkalis in the cement, reducing the concrete permeability, and increasing its tensile strength. Historically fly ash was almost free and readily available, but with the phasing out of coal-fired power plants due to cheap natural gas and increasingly stringent pollution controls, fly ash has become scarce in many parts of the country. This situation only promises to get worse.

2.5.6 Mitigation by 20–30% fly ash and ferronickel slag(FNS):

(AK Saha, 2018), the use of 20–30% fly ash as cement replacement is considered as an adequate ASR mitigating measure of FNS fine aggregate.

This study investigates the potential alkali silica reaction (ASR) of ferronickel slag (FNS) aggregate, which is a by-product of nickel production. A class F fly ash was used as a possible ASR mitigation in accelerated mortar bar test (AMBT) specimens containing 50% FNS. There were visible surface cracks on the specimens using no fly ash or 10% fly ash. Use of 20% fly ash reduced expansion by 45% as compared to that with 10% fly ash. In accordance with the expansion limits of Australian Standard, the mixtures using 20 and 30% fly ash were categorized as slowly reactive and nonreactive, respectively. Thermogravimetric analysis (TGA) and microstructural observations confirmed the effectiveness of fly ash in reducing Portlandite content that reduced the ASR expansion. Therefore, the use of 20–30% fly ash as cement replacement is considered as an adequate ASR mitigating measure of FNS fine aggregate.

2.5.7 Mitigation by fly ash and GGBS (Murari, 2008):

The alkali silica reaction (ASR) is a pathological manifestation of chemical origin and high gravity that can negatively affect the mechanical properties and durability of important concrete structures, even with short time in service. The reaction results from the interaction of Portland cement alkalis and other sources (internal and external to concrete) with the reactive silica of the aggregate. Several studies are under development about the best approach for the mitigation of ASR. The use of supplementary cementitious materials (SCM) has been widely accepted. One of the first SCM studied was the fly ash and, in recent years, the granulated blast furnace slag(GGBS) has also been fairly addressed in research. To have the expected efficacy, fly ash and granulated blast furnace slag must present some peculiar characteristics such as high total concentration of silica, alumina and hematite, high fineness and reduced alkalis content. The protection mechanism offered by fly ash and granulated slag involves not only the pozzolanic action, but also the possibility of fixing the alkalis in the pozzolanic C-S-H, reducing the CaO/SiO_2 ratio of the C-S-H formed by the Portland clinker and reducing the permeability of the concrete. Currently, the use of SCM is still the best approach in the ASR mitigation because, in addition to offering technical advantages, it also contributes to reducing the environmental impact caused by industries in different segments, either by reducing the CO_2 released into the atmosphere or by reusing by-products.

2.5.8 Mitigation by soda lime glass:

Mary Ann Adajar and others stated that: Waste soda lime glass was utilized as a component in concrete mixture replacing coarse aggregates at varying percentages (Mary Ann Adajar, et al., 2019).

The use of solid wastes as an alternative component in concrete production is one possible innovative effort to alleviate disposal problem, reduce environmental degradation and reduce the production cost of concrete products. However, one drawback of the use of soda-lime glass in the concrete mix is its ability to produce alkali-silica reaction (ASR). Class-F fly ash was added in the mix as supplementary cementitious material replacing 30% of cement by volume. The potential alkali-silica reactivity (ASR) of concrete with soda-lime glass was determined and the effectiveness of fly ash as a mitigating agent of ASR was evaluated. Test results showed that the replacement of soda-lime glass to coarse aggregates produced an increase in compressive strength of concrete up to 30% replacement. An empirical model was formulated to predict the compressive strength at percentage substitution of soda-lime glass to coarse aggregates. From flexural strength test, results showed that there is a minimal reduction in the flexural strength of concrete as the percentage replacement of soda-lime glass was increased but the reduction can be considered as insignificant. Concrete beam specimens with soda-lime glass experienced a reduction in ductility as manifested by the stress-strain behavior. With the use of class F fly-ash as supplementary cementitious material replacing 30% of cement, the utilization of soda-lime glass can be maximized up to 30% substitution to coarse aggregate without deleterious expansion. Class F fly-ash in moderate level was proven as an effective mitigating agent of ASR in concrete production up to 30% substitution of soda-lime glass to coarse aggregate.

CHAPTER THREE

MATERIALS AND TESTING

CHAPTER THREE

MATERIALS AND TESTING

3.1 Introduction

This chapter three describes firstly, the materials used in this research such as cement, aggregates, fly ash (appendix B-10 photo) and natural pozzolan. Secondly, the chapter includes the laboratory testing results conducted.

3.2 The Materials:

Prior to the construction of the concrete works, the Contractor carried out extensive tests on the proposed materials to be used in the projects and during execution of the concrete works. The following are the main materials which have been tested in accordance to the specification requirements:

3.2.1 The Cement:

Cement proposed to be used in Merowe Dam Project (MDP- appendix B-4, B-5 & B-6), is Type I 42.5N 28 days compressive strength OPC (Ordinary Portland Cement) with low alkali content and shall be sampled and tested for strength and physical properties, and chemical analysis shall be carried out as set out in (EN 196, EN 197and ASTM Specification C 150) In Dam Complex of Upper Atbara Project (DCUAP- appendix B-3, B-5 & B-7), cement proposed 42.5 N 28 days compressive strength Slag Cement CEM III/B which contains 30% OPC (Ordinary Portland Cement) 70% GGBS (Ground Granulated Blast Furnace Slag).

A - Determination of Alkalis Content in OPC:

The obtained cement quality certificates and collected some samples from proposed mills suppliers (Marine Cement(MC), Egyptian Cement Company(ECC) and Guangxi Yufeng Cement(GYC) and sent to third party laboratories for conducted physical properties and chemical analysis. The following are the tests carried out on the cement samples and mill quality certificates as shown in Table (3.1).

Table 3.1Chemical Analysis, determination of Alkali content Merowe Dam Project, Concrete Trial Mixes, Test Report CCMD, 2004.:

Item	Result %	Requirements
Silicon Dioxide(SiO_2)	19.1	
Aluminum Oxide(Al_2O_3)	8.1	
Ferric Oxide (Fe_2O_3)	2.7	
Calcium Oxide (CaO)	61.8	
Magnesium Oxide (MgO)	2.3	Max,6.0%
Sulfur Trioxide (SO_3)	2.6	Max,3.5%
Potassium Oxide (K_2O)	0.20	
Sodium Oxide (Na_2O)	0.19	
Loss On Ignition(LOI)	2.3	3.0%
Na_2O Equivalent	0.32	Max. 0.60%

Na_2O Equivalent Calculation:

According to the Equation, $Na_2OE = Na_2O + 0.658\ K_2O$

$Na_2OE = 0.19 + 0.658 * 0.20 = \underline{0.3216}$

Table 3.2 Chemical Analysis, determination of Alkali content –E. Cement Company (ECC) mill Cement Quality Certificate-March 2004.

Item	Result %	Standard Requirements
Silicon Dioxide(SiO_2)	19.93	
Aluminum Oxide(Al_2O_3)	4.69	
Ferric Oxide (Fe_2O_3)	3.9	
Calcium Oxide (CaO)	64.4	
Magnesium Oxide (MgO)	1.6	Max,6.0%
Sulfur Trioxide (SO_3)	2.25	Max,3.5%
Potassium Oxide (K_2O)	0.20	
Sodium Oxide (Na_2O)	0.19	
Chloride (CL)	0.060	
Insoluble Residue (IR)	0.44	
Loss On Ignition(LOI)	3.76	3.0%
Tricalcium Silicate (C_3S	67.14	
Dicalcium Silicate (C_2S)	6.49	
Tricalcium Aluminate (C_3A)	5.83	
Tetra calcium Aluminoferrite(C4AF)	11.86	
Alkalis Equivalent (AE)	0.32	Max. 0.60%

Na_2O Equivalent Calculation:

According to the Equation, $Na_2OE = Na_2O + 0.658\ K_2O$

$Na_2OE = 0.19 + 0.658 * 0.20 = \underline{0.3216}$

The determination of the alkali content of the cement samples was carried out according to European Standard EN 196.

Table 3.3 Chemical Analysis, determination of Alkali content, Merowe Dam Project, Final Test Report on Concrete Aggregates, Cement and Fly ash, 2009.

Sample NO.	Item	Certified Values	Values obtained	Standard Requirements ASTM C150 EN197
1	Na_2O %	0.10 ± 0.01	0.10	
	K_2O %	0.49 ± 0.02	0.50	
	Na_2O Equivalent %	0.42	0.43	Max. 0.60%
2	Na_2O %	0.10 ± 0.01	0.11	
	K_2O %	0.75 ± 0.03	0.72	
	Na_2O Equivalent %	0.59	0.58	Max. 0.60%

Na_2O Equivalent Calculation:

According to the Equation 2.1, $Na_2OE = Na_2O + 0.658\ K_2O$

$Na_2OE = 0.10 + 0.658 * 0.50 = \underline{0.429}$

Na_2O Equivalent Calculation:

According to the Equation 2.1, $Na_2OE = Na_2O + 0.658\ K_2O$

$Na_2OE = 0.11 + 0.658 * 0.72 = \underline{0.5837}$

Table 3.4 Chemical Analysis, determination of Alkali content Merowe Dam Project, Final Test Report on Concrete Aggregates, Cement and Fly ash, 2009.

Item	G.Y Cement %	Chemical Requirements According to ASTM C150 %	Chemical Requirements According to EN 197 %
Na_2O %	0.10		
K_2O %	0.58		
Na_2O Equivalent %	0.48	Max. 0.60	Max. 0.60

Na_2O Equivalent Calculation:

According to the Equation, $Na_2OE = Na_2O + 0.658\ K_2O$

$Na_2OE = 0.10 + 0.658 * 0.58 = \underline{0.4816}$

Table 3.5 Chemical Analysis, determination of Alkali content Merowe Dam Project, Final Test Report on Concrete Aggregates, Cement and Fly ash, 2009.

Item	ECC Cement %	Chemical Requirements According to ASTM C150 %	Chemical Requirements According to EN 197 %
Na_2O %	0.44		
K_2O %	0.30		
Na_2O Equivalent %	0.64	Max. 0.60	Max. 0.60

Na_2O Equivalent Calculation:

According to the Equation 2.1, $Na_2OE = Na_2O + 0.658\ K_2O$

$Na_2OE = 0.44 + 0.658 * 0.30 = \underline{0.6374}$

B - Determination of Alkalis Content in GGBS Cement, (appendix B-9)

The cement used in the concrete for Dam Complex of Upper Atbara Project is Ground Granulated Blast Furnace Slag and the following are the samples taken from the Cement Testing Results Certificates (Dam Complex of Upper Atbara Project) as shown in the table below:

Table 3.6 Chemical Analysis, Determination of Alkali Content

Item	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7
Na_2O	0.22	0.22	0.23	0.23	0.22	0.22	0.22
K_2O	0.37	0.37	0.37	0.37	0.36	0.37	0.36
Na_2Oe	0.46	0.46	0.47	0.47	0.46	0.46	0.46
Item	Sample 8	Sample 9	Sample 10	Sample 11	Sample 12	Sample 13	Sample 14
Na_2O	0.16	0.15	0.16	0.14	0.15	0.12	0.12
K_2O	0.55	0.55	0.55	0.56	0.58	0.56	0.56
Na_2Oe	0.52	0.51	0.52	0.51	0.53	0.49	0.49
Item	Sample 15	Sample 16	Sample 17	Sample 18	Sample 19		
Na_2O	0.18	0.17	0.2	0.19	0.21		
K_2O	0.52	0.55	0.55	0.54	0.52		
Na_2Oe	0.52	0.53	0.56	0.55	0.55		

Chemical Requirements for low Alkali Cement According to ASTM C150 & EN 197, Max.0.60 %

Na_2O Equivalent Calculation:

According to the Equation, $Na_2OE = Na_2O + 0.658\ K_2O$

3.2.2 Aggregates:

All aggregates in Merowe Dam Project, coarse and fine fraction proposed and used for concrete production are crushed material from quarry Umm Duweima (UDQ), located at the right bank of the Nile River about 3 *km* upstream the Merowe Dam axis. The parent rock is grey granite, granitic gneiss, pegmatite and biotite gneiss crushed into fractions 0 – 9.5 mm, 9.5 – 19 mm, 19 - 38 mm & 38 - 76 mm, in accordance to the MDP specification requirements.

Natural processed washed sand from Wadi Abu Sibba downstream left bank of the Nile River was used as fine fraction in percentage of 20% of total fine aggregate used in concrete mix.

All aggregates in Dam Complex of Upper Atbara Project, coarse and fine fractions proposed and used for concrete production are crushed material from quarry Jebel Aklaiyit, hauled 20 km, mainly basalt, granite, migmatite crushed into fractions 0 - 5 mm, 5 - 16 mm, 16 - 32 mm & 32 - 63 mm, in accordance to the DCUAP specification requirements.

The aggregates tested in accordance to the ASTM C 33 requirements for quality before and during the construction of the concrete works in Merowe Dam and Dam Complex of Upper Atbara Projects.

3.2.3 Fly ash & Natural Pozzolan

A – Fly ash:

Fly ash Type F (ASTM C618), which was proposed and used in Merowe Dam Project to replace partially cement for purpose of decreasing the heat of hydration in mass concrete, increasing workability, decreasing seepage and mitigating Alkali Silica Reactivity (ASR). The material was imported from China and was tested by supplier as well as the third party Laboratories - Ministry of Science& Technology Industrial Research & Consultancy Centre – Khartoum Sudan-June 2004 and University of Karlsruhe Institute Germany.

Table 3.7 Fly ash class F chemical & physical properties (according to ASTM C618 & C311): Hans Jürgen Huade, Merowe Dam Project – Germany, 2005.

Description	Required limits	Testing Results	Properties
$SiO_2+AL_2O_3+Fe_2O_3$, Min.%	70.0	93.4	Chemical
SO_3 Max,%	5.0	0.78	Chemical
Moisture Content, Max.%	3.0	0.09	Chemical
Loss On Ignition(LOI), Max.%	6.0	-	Chemical
Fineness wet sieve retain on 45µm, max.%	34.0	10	Physical
Strength, with OPC at 7days, min.%	75	76.4	Physical
Strength, with OPC at 28days, min.%	75	86.7	Physical
Water requirement, max,% of control	105	95	Physical
Soundness, Autoclave expansion or extraction, max,%	0.8	0.675	Physical
Drying Shrinkage: Increase at 28 days %	0.03	0.016	Physical

Table 3.8 Fly ash class F chemical properties (according to ASTM C618 & C311): Hans Jürgen Huade, Merowe Dam Project – Germany, 2005.

Components	S_1Results %	S_2 Results %	ASTM C 618 Requirements
CaO	5.05	4.52	-
SiO_2	53.3	55.0	SiO_{2+} Al_2O_{3+} Fe_2O_3 Min. 70 %
Al_2O_3	29.85	28.77	
Fe_2O_3	4.64	5.07	
MgO	1.28	1.36	-
K_2O	0.53	0.65	-
Na_2O	0.20	0.20	-
SO_3	0.70	0.59	Max. 5.0
Chloride	0.003	0.003	-
LOI	3.11	1.16	Max. 6.0
Na_2O equivalent	0.55	0.63	Max. 1.5

Table 3.9 Fly ash class F Physical properties (according to ASTM C618 & C311): Hans Jürgen Huade, Merowe Dam Project – Germany, 2005.

Tests	S_1	S_2	S_3	S_4	S_5	ASTM C 618
Density gm/cm^3	2.290	2.338	2.30	2.36	2.326	-
Density, max. variation from average%	1.4	0.7	1.0	1.6	0.1	5
Fineness amount on 45µm sieve, max.%	6.2	7.3	30	8.2	6.4	Max. 34
Strength activity index at 7 days, % of control	82	80	80	83	81	Min. 75
Strength activity index at 28days,% of control	88	97	96	100	94	Min. 75
Water Requirement, Max. % of control	99	99	99	99	98	105

B - Natural Pozzolan:

The Contractor proposed to replace the imported Chinese Fly Ash Type F (ASTM C618) with a local natural pozzolan, if the material fulfilled the requirements. One of the sources is offered by the local enterprise “Nile Silicon Co.” who offers the excavation grinding of pozzolan (Hans Jürgen Huade, 2005).

The material proposed to be quarried from Buyda desert central volcanic field, mainly from Abu Serjain mountain, 6 *km* West of Bir Sani. It appears there in the form of boulders at the surface, but also in form of “ash” layers (1 to 10mm particle size) in the ground. The total size of the volcanic field is 48 *km* by 11 *km*. The area for quarrying in the first is estimated with 390000m^2 and the useful layer thickness is estimated with 2*m* (Hans Jürgen Huade, 2005).

C - Results of Natural Pozzolan from Abu Serjain mountain

The following are the concrete mix performed, mix proportions 1:2:4:

Mix1: OPC only

Mix2: 90% OPC+10% pozzolan powder using natural aggregate

Mix3: 80% OPC+20% pozzolan powder using natural aggregate

Mix4: 90% OPC+10% pozzolan powder using crushed coarse aggregate

Mix5: 80% OPC+20% pozzolan powder using crushed coarse aggregate

Mix6: 50% OPC+50% pozzolan powder, mix proportion 1:6

Mix7: 50% OPC+50% pozzolan powder, mix proportion 1:7

The 7days & 28days compressive strength (N/mm^2) of the above mixes are illustrated in the following Table (3.10):

Table 3.10 Natural pozzolan (Hans Jürgen Huade, 2005) – Testing results

Mix NO.	7 days comp. strength	28 days comp. strength
1	16	21
2	15	20
3	20	25
4	18	21
5	15	20
6	1.8	2.2
7	0.8	1.4

Table 3.11 chemical properties of natural pozzolan (according to ASTM C618 & C311): Hans Jürgen Huade, Merowe Dam Project – Germany, 2005.

Description	limits	Results	Properties
$SiO_2+AL_2O_3+Fe_2O_3$, Min.%	70.0	-	Chemical
SO_3 Max,%	5.0	0.18	Chemical
Moisture Content, Max.%	3.0	-	Chemical
Loss On Ignition(LOI), Max.%	6.0	-	Chemical
Chloride %	-	0.04	Chemical
Na_2O equivalent, Max.%	1.5	4.53	Chemical

The strength activity index was determined for 5 samples, showed results ranged from 74 to 78% at 28 days according to ASTM C 618.

3.3 Laboratory Testing

3.3.1 Test Method of ASR of Aggregate used in (MDP):

3.3.1.1 ASR Chemical Method ASTM C 289:

Seven crushed aggregate samples sourced from Umm Duweima Quarry (UDQ), Merowe Dam Project Site were sent for laboratory testing evaluation. The samples include crushed & natural sand, 9.5*mm*, 19*mm* and 38*mm*.

This test method covers chemical determination of the potential reactivity of an aggregate with alkalis in Portland cement concrete as indicated by the amount of reaction during 24 h at 80°C between 1 N sodium hydroxide solution and aggregate that has been crushed and sieved to pass a 300-μm sieve and be retained on a 150-μm sieve. This test method may be used in combination with other methods to evaluate the potential reactivity of siliceous aggregate with alkalis in Portland-cement concrete. The amount of reaction is dependent upon the dissolved silica and the reduction in alkalinity of the solution. The dissolved silica was determined by the solution having been filtered and analyzed and the reduction in alkalinity of the solution determined by titration with acid. The test was repeated three times (A, B &C) for all fractions of aggregates sizes: 9.5mm, 19.0mm, 38.0mm, Natural Sand, Crushed Sand and mixed sample (20%NS + 80%CS). The results were then checked against ASTM C 289 Standard Evaluation Curve. If all the results lie to the left of the Standard Evaluation Curve, the aggregate is considered to be innocuous; if any of the results lie to the right of the Standard Evaluation Curve, the aggregate may give rise to deleterious expansion when used in high alkali content concrete the results are shown.

Table3.12 Values of Dissolved Silica (Sc) and Reduction in Alkalinity (Rc), Merowe Dam Project, Concrete Trial Mixes, Test Report CCMD, 2004.

Aggregate size	Test repeated portion	Quantity of Rc mmol/l	Quantity of Sc mmol/l
9.5mm	A	175	27.6
	B	200	28
	C	150	27.3
19.0mm	A	150	20
	B	160	19.3
	C	150	21.3
38mm	A	200	16.7
	B	175	17.6
	C	200	18.3
Natural sand	A	250	39.3
	B	225	33.3
	C	250	44
Crushed sand	A	150	14
	B	175	11
	C	200	12
Mixed sample	A	250	16.7
	B	225	15.3
	C	250	16
20%natural sand + 80%crushed sand	A	200	14.3
	B	175	17.3
	C	200	18.3

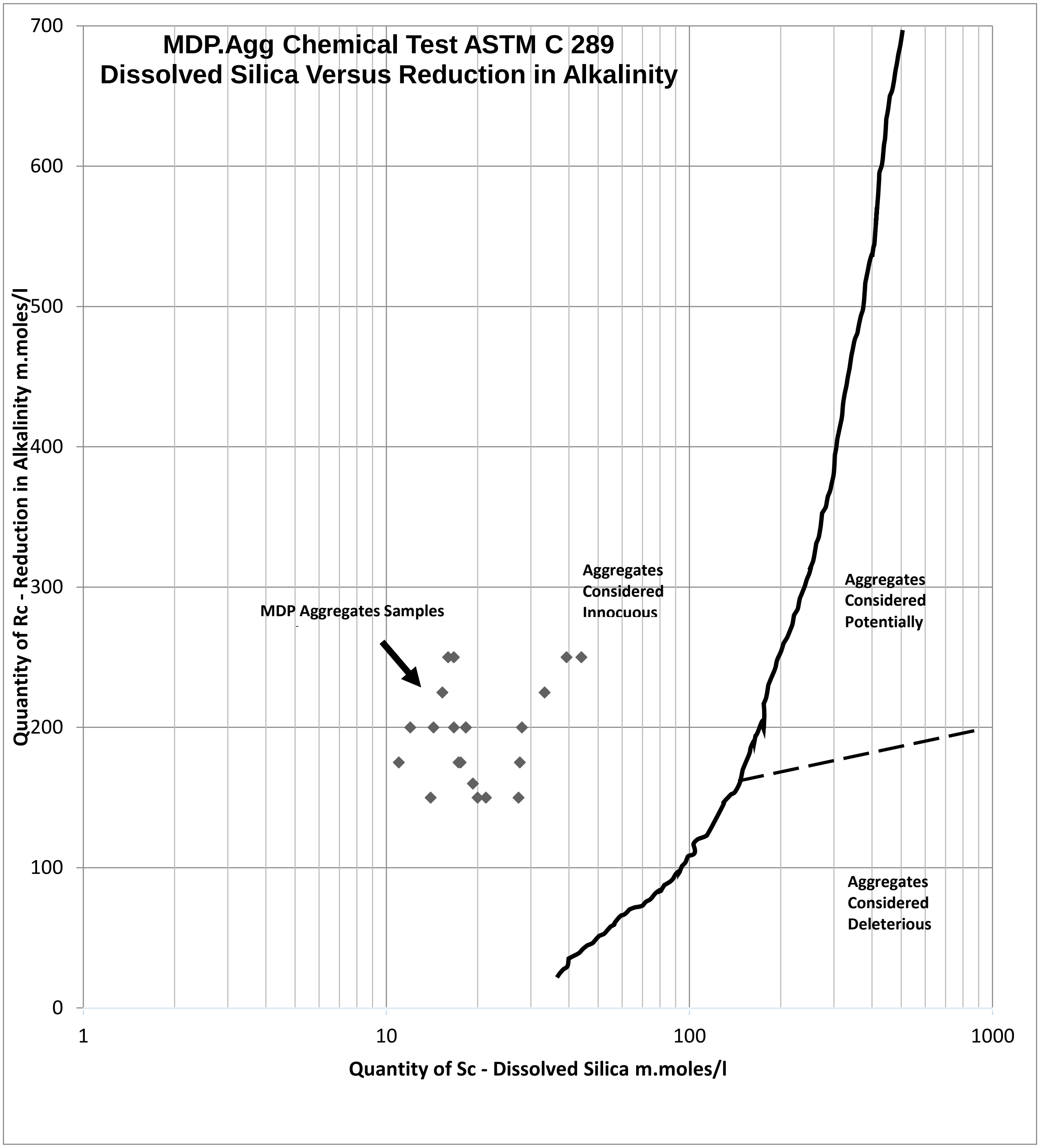

Fig 3.1A Position of the aggregate samples tested in the diagram Sc versus Rc according to ASTM C 289 Standard Evaluation Curve, Chemical Method.

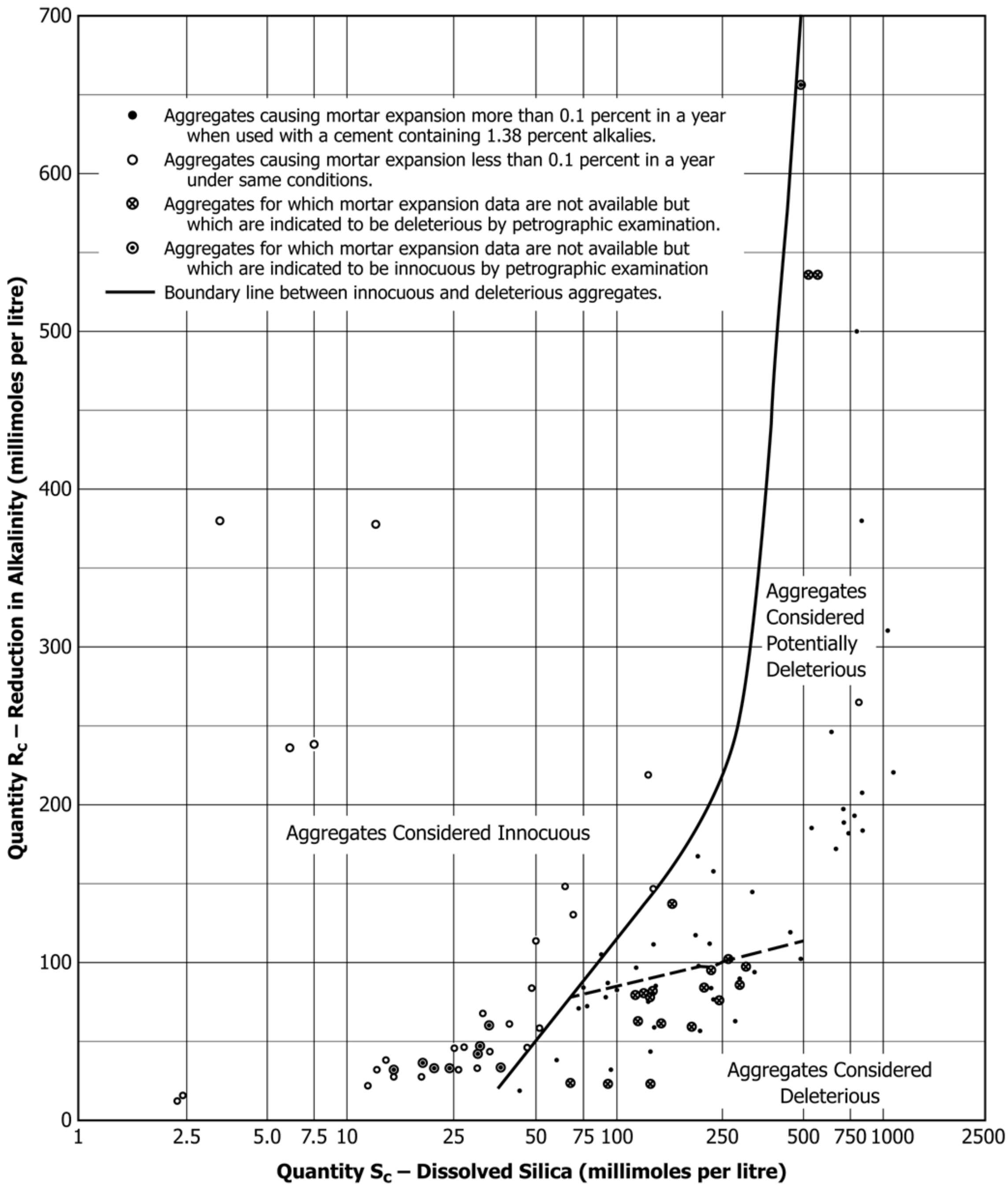

Fig 3.1B ASTM C 289 Standard Evaluation Curve, Chemical Method.

3.3.1.2 ASR Mortar-Bar Method ASTM C 227:

Table3.13: Grading Requirements (ASTM Designation: C227):

Sieve Size		
Passing	Retained on	Mass %
4.75-mm (No. 4)	2.36-mm (No. 8)	10
2.36-mm (No. 8)	1.18-mm (No. 16)	25
1.18-mm (No. 16)	600-µm (No. 30)	25
600-µm (No. 30)	300-µm (No. 50)	25
300-µm (No. 50)	150-µm (No. 100)	15

The test using Ordinary Port Land Cement with 0.47% sodium oxide, 1.12% potassium oxide and 1.21% calculated sodium oxide equivalent. This sample of the OPC is not used in the concrete construction of MDP, it is only used in the test for evaluation of UDQ aggregates whether the aggregates are reactive or nonreactive. the results of expansion measurements which were obtained in a 3-month period are shown in the following Table (3.14).

Table 3.14: Percentage expansion of mortar bars subjected to the ASTM C 227 test over a 3-month period using OPC of 1.21% sodium oxide equivalent, Merowe Dam Project, Concrete Trial Mixes, Test Report CCMD, 2004.

Time in days	M.Bar No.1	M.Bar No.2	M.Bar No.3	M.Bar No.4
0	0.000	0.000	0.000	0.000
15	0.024	0.030	0.030	0.026
30	0.030	0.036	0.035	0.031
60	0.032	0.040	0.038	0.033
90	0.034	0.042	0.040	0.036

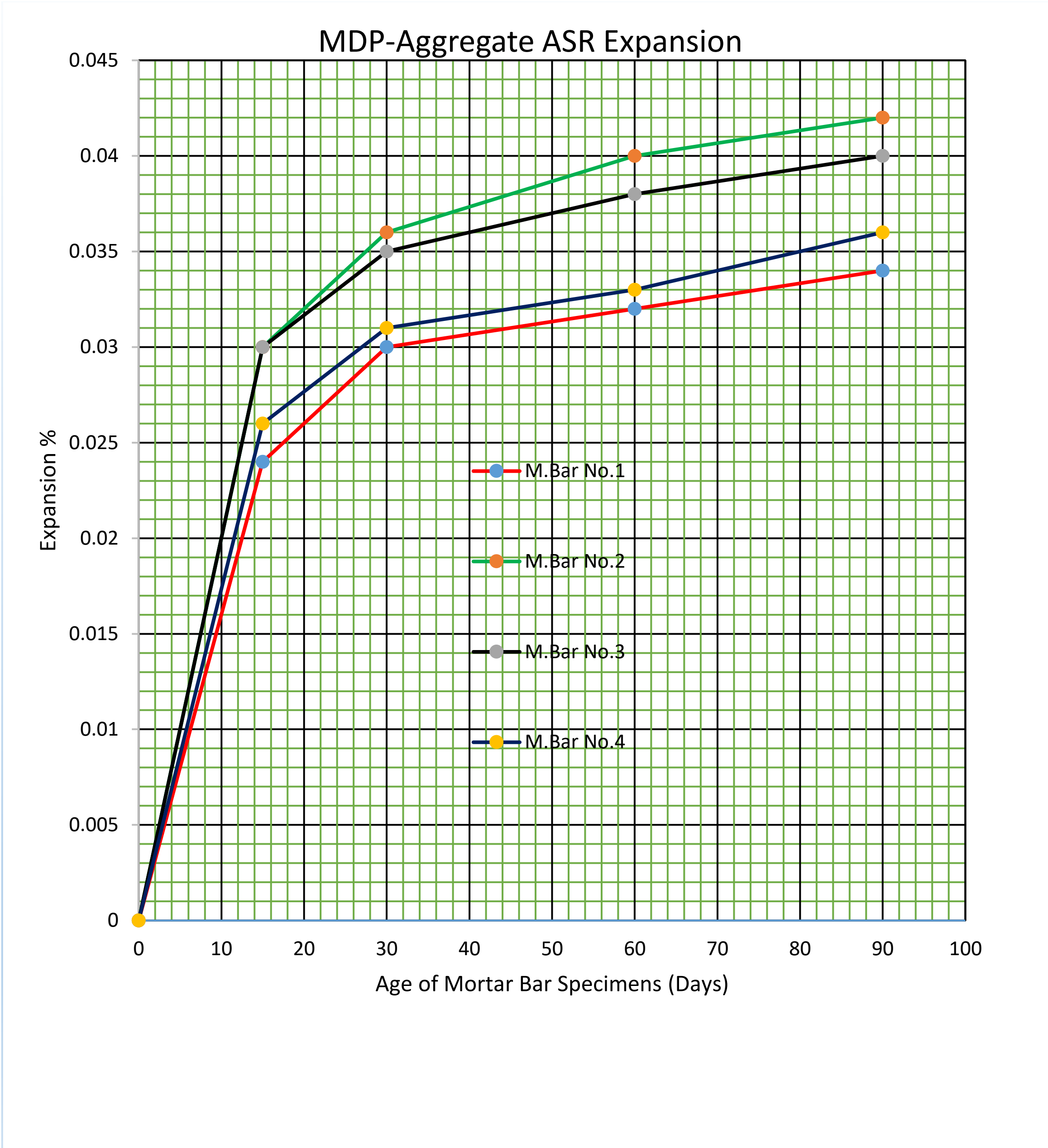

Fig 3.2 expansion of mortar bars subjected to the ASTM C 227 test over a 3-month period using OPC of 1.21% sodium oxide equivalent and Umm Dewiema quarry crushed aggregate (Merowe Dam Project, Concrete Trial Mixes, Test Report CCMD, 2004).

3.3.1.3 ASR Petrographic Examination ASTM C 295:

Standard Guide for Petrographic Examination of Aggregate for Concrete:

The samples were prepared in accordance with the procedure for examination of natural and crushed sand samples in ASTM C295. From representative portions of 2 sand samples, three different sieve fractions were produced and finally thin sections were prepared. The thin sections were examined by a polarizing stereoscopic microscope. Table 3.15: list of thin sections to be used for the examination by microscope (appendix B-8 photo) Merowe Dam Project, Final Test Report on Concrete, 2009.

Sand sample	Origin	Thin Sections No,
Natural Sand	Wadi Abu Sibba	1,2,3
Crushed Sand	Umm Deiwema Quarry	4,5

Two representative sand specimens have been classified into three grain size fractions (<600μm,600-1180μm,1180-2360μm). From these fractions thin sections were prepared. Five thin sections have been analyzed considering the different grain size fractions. The initial rock is determined as intermediary magmatite which includes 52 to 65%quartz and between 30 to 45% feldspar. It is granite.

3.3.1.4 X-Ray Diffraction (XRD):

The powdered material of the sand sample was analyzed by x-ray diffraction. Calibration curves from the essential rock forming minerals permit semi-quantitative mineral analysis table3.16. There are no obvious differences in the minerals composition of the different sand samples in the XRD spectra visible.

Table3.16: Results of semi – quantitative minerals analysis of the samples by XRD Merowe Dam Project, Final Test Report on Concrete, 2009.

Sand Sample No.	Quartz	Feldspar Group	Mica Group	Keolinite/ Chlorite	Calcite	Mon-crystalline phases
Nat. sand1	Yes	Yes	Yes	No	No	Not detected
Nat. sand2	Yes	Yes	Yes	No	No	Not detected
Nat. sand3	Yes	Yes	Yes	No	No	Not detected
Cru.sand4	Yes	Yes	Yes	No	No	Not detected
Cru.sand5	Yes	Yes	Yes	No	No	Not detected

3.3.1.5 ASR Mortar-Bar Method Accelerated Method ASTM C 1260:

This test method provides the means for detecting the potential of an aggregate used in concrete for undergoing alkali-silica reaction and resulting potentially deleterious internal expansion within 16 days. Sieve size according to ASTM C1260 and required weight % of aggregate for alkali aggregate reaction test.

Table3.17: Grading Requirements (ASTM Designation: C1260):

Sieve Size		
Passing	Retained on	Mass %
4.75-mm (No. 4)	2.36-mm (No. 8)	10
2.36-mm (No. 8)	1.18-mm (No. 16)	25
1.18-mm (No. 16)	600-µm (No. 30)	25
600-µm (No. 30)	300-µm (No. 50)	25
300-µm (No. 50)	150-µm (No. 100)	15

Proportioning of the dry materials for the test mortar using 1 part of cement to 2.25 parts of graded aggregate by mass. The quantities of dry materials mixed at one time in the batch of mortar and for the three specimens equal 440 g of cement and 990 g of aggregate. The water to cement ratio equal to 0.47 by mass.

Each mold Placed in the moist cabinet immediately after molds have been filled. The specimens remained in the molds for 24 h. The specimens removed from the molds and protected from loss of moisture, properly identified and an initial comparator reading was made.

The three mortar specimens of each aggregate sample were placed in separate containers with sufficient 1 N NaOH, at 80°C for the samples to be totally immersed.

Two tests were carried out for Egyptian Company Cement (ECC) of alkali content (Na_2Oe equal 0.64%) mixed with both natural and crushed sand. Also another two tests were carried out for Guangxi Yufeng Cement (GYC) of alkali content (Na_2Oe equal 0.48%) - Chinese cement - mixed with natural and crushed sand. The following are the results of the four tests illustrated as follows:

Table 3.18. Test one Natural Sand mixed with ECC Cement of 0.64% Na_2Oe (Merowe Dam Project Final Test Report on Concrete LI, Germany, 2009.

Age (days)	S_1- Expansion%	S_2- Expansion%	S_3- Expansion%	Standard Limit %
2	0.0	0.0	0.0	0.1
3	0.005	0.004	0.005	0.1
8	0.010	0.009	0.011	0.1
11	0.030	0.029	0.028	0.1
14	0.035	0.036	0.038	0.1
16	0.038	0.037	0.039	0.1

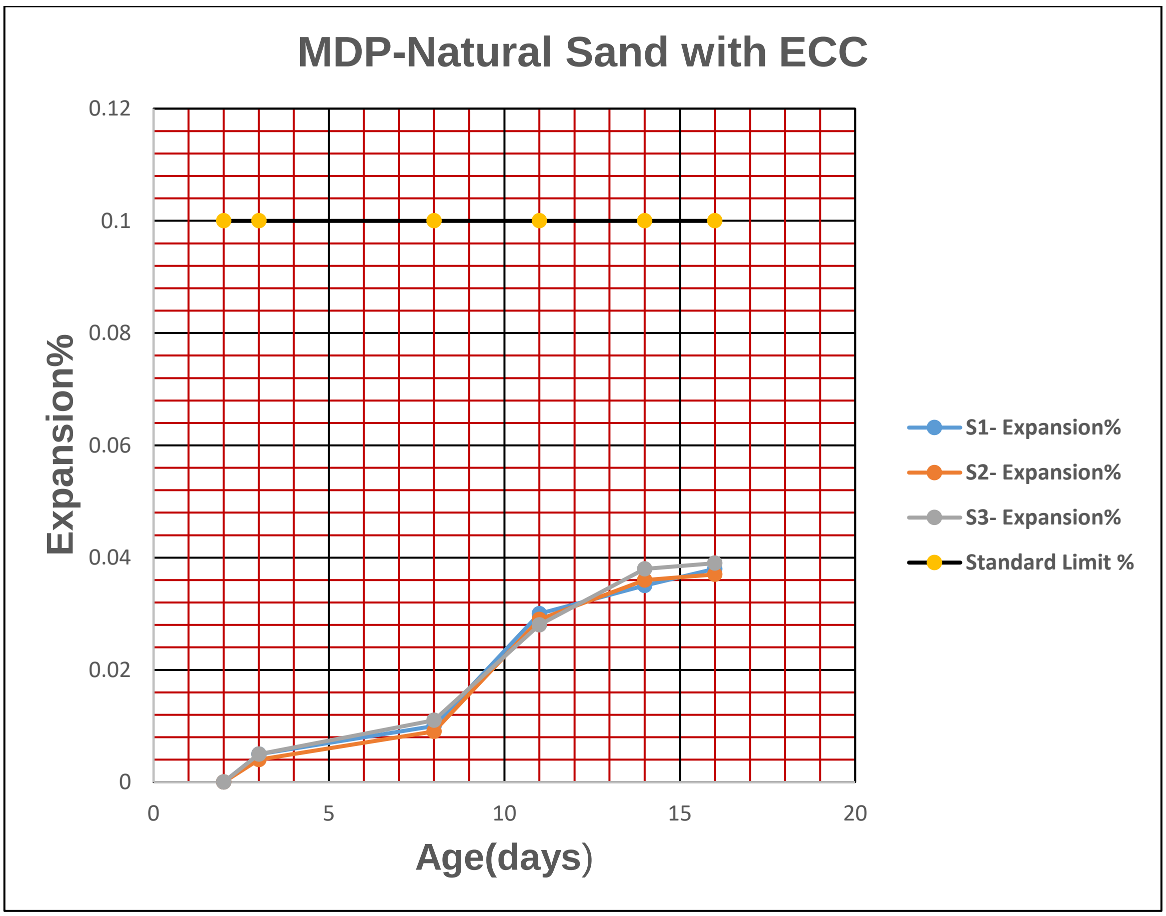

Fig 3.3: Test one natural sand mixed with ECC cement of 0.64% Na_2Oe (Merowe Dam Project Final Test Report on Concrete LI, Germany, 2009.

ASTM C 1260 Accelerated Method.

Table 3.19 Test two Crushed Sand mixed with ECC cement of 0.64% Na_2Oe (Merowe Dam Project Final Test Report on Concrete LI, Germany, 2009.

ASTM C 1260 Accelerated Method.

Age (days)	S_1- Expansion%	S_2- Expansion%	S_3- Expansion%	Standard Limit %
2	0.0	0.0	0.0	0.1
3	0.002	0.004	0.005	0.1
8	0.020	0.021	0.023	0.1
11	0.037	0.035	0.038	0.1
14	0.043	0.044	0.042	0.1
16	0.050	0.049	0.050	0.1

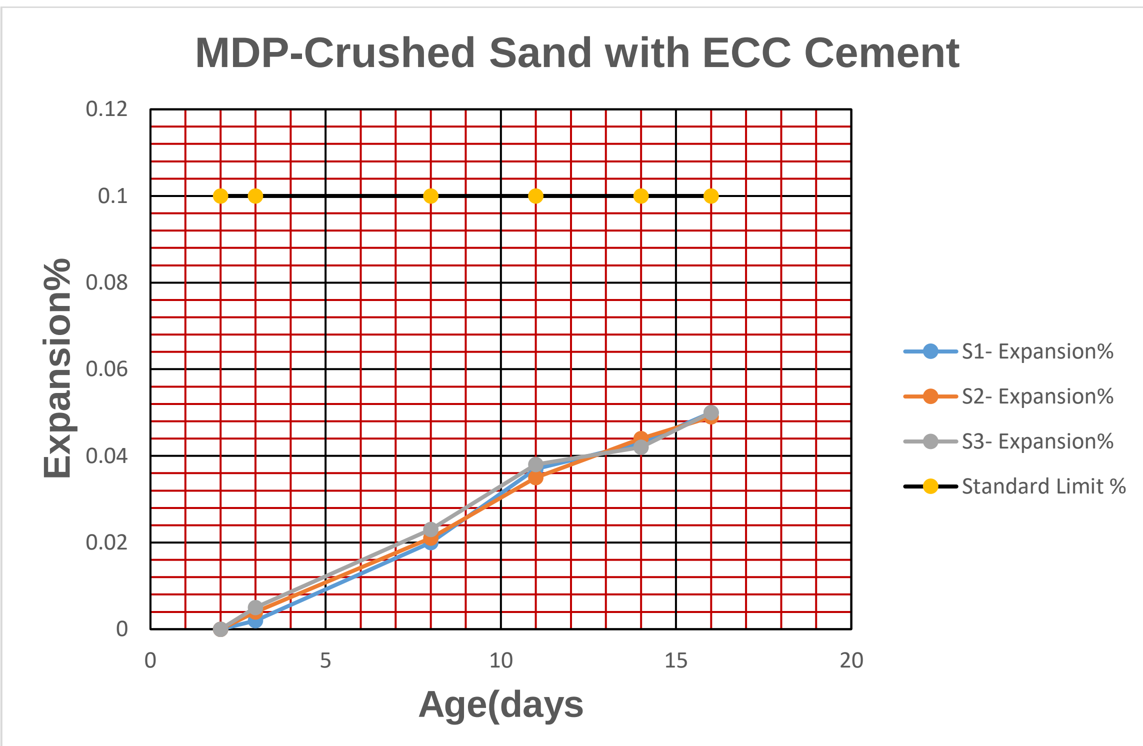

Fig3.4: Test two crushed sand mixed with ECC cement of 0.64% Na_2Oe (Merowe Dam Project Final Test Report on Concrete LI, Germany, 2009. ASTM C 1260 Accelerated Method

Table 3.20 Test three natural sand mixed with GYC cement of 0.48% Na_2Oe (Merowe Dam Project Final Test Report on Concrete LI, Germany, 2009. ASTM C 1260 Accelerated Method.

Age (days)	S_1- Expansion%	S_2- Expansion%	S_3- Expansion%	Standard Limit %
2	0.0	0.0	0.0	0.1
3	0.008	0.009	0.010	0.1
8	0.017	0.018	0.019	0.1
11	0.021	0.022	0.025	0.1
14	0.036	0.038	0.039	0.1
16	0.041	0.040	0.042	0.1

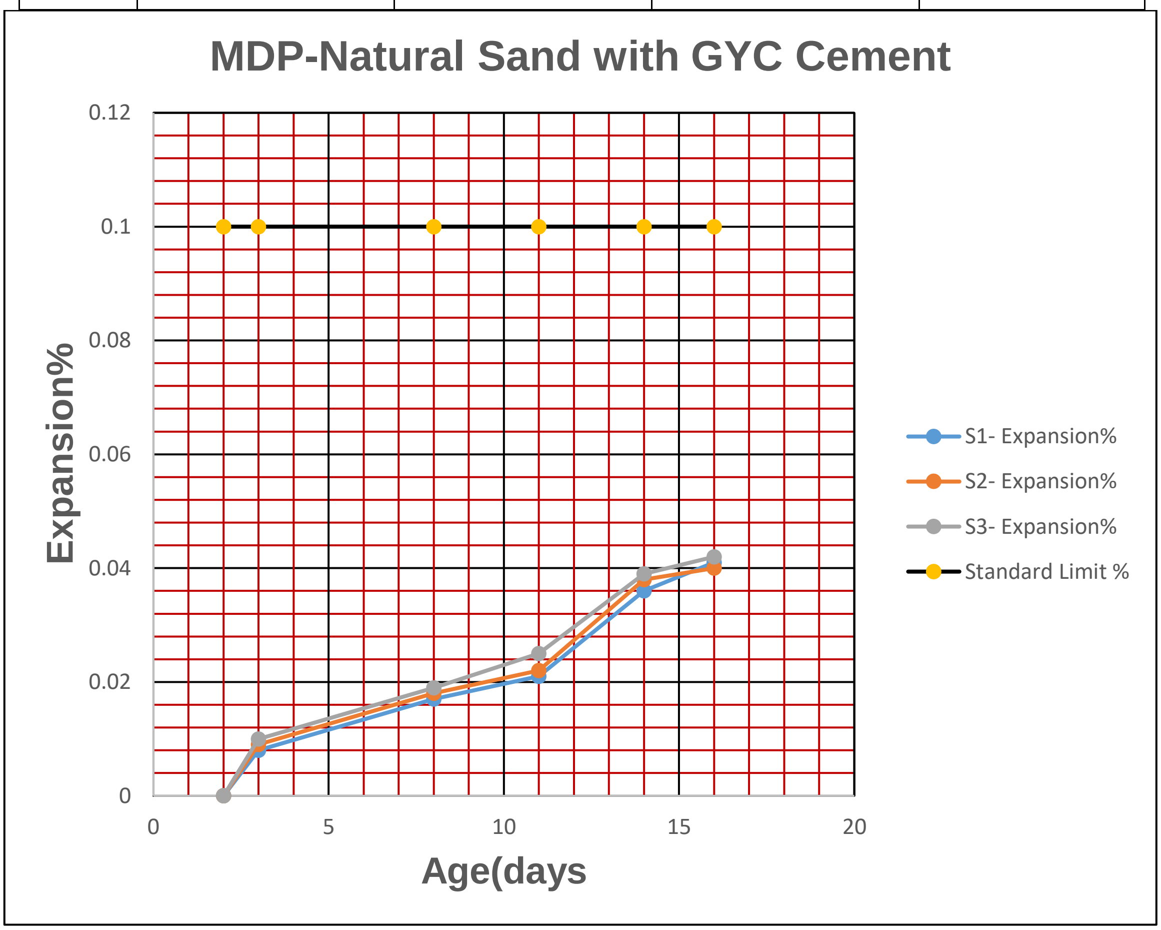

Fig3.5: Test three natural sand mixed with GYC cement of 0.48% Na_2Oe (Merowe Dam Project Final Test Report on Concrete LI, Germany, 2009. ASTM C 1260 Accelerated Method.

. Table 3.21Test four crushed sand mixed with GYC cement of 0.48% Na_2Oe (Merowe Dam Project Final Test Report on Concrete LI, Germany, 2009. ASTM C 1260 Accelerated Method.

Age (days)	S_1- Expansion%	S_2- Expansion%	S_3- Expansion%	Standard Limit %
2	0.0	0.0	0.0	0.1
3	0.005	0.006	0.005	0.1
8	0.020	0.009	0.008	0.1
11	0.038	0.039	0.040	0.1
14	0.049	0.048	0.050	0.1
16	0.050	0.051	0.050	0.1

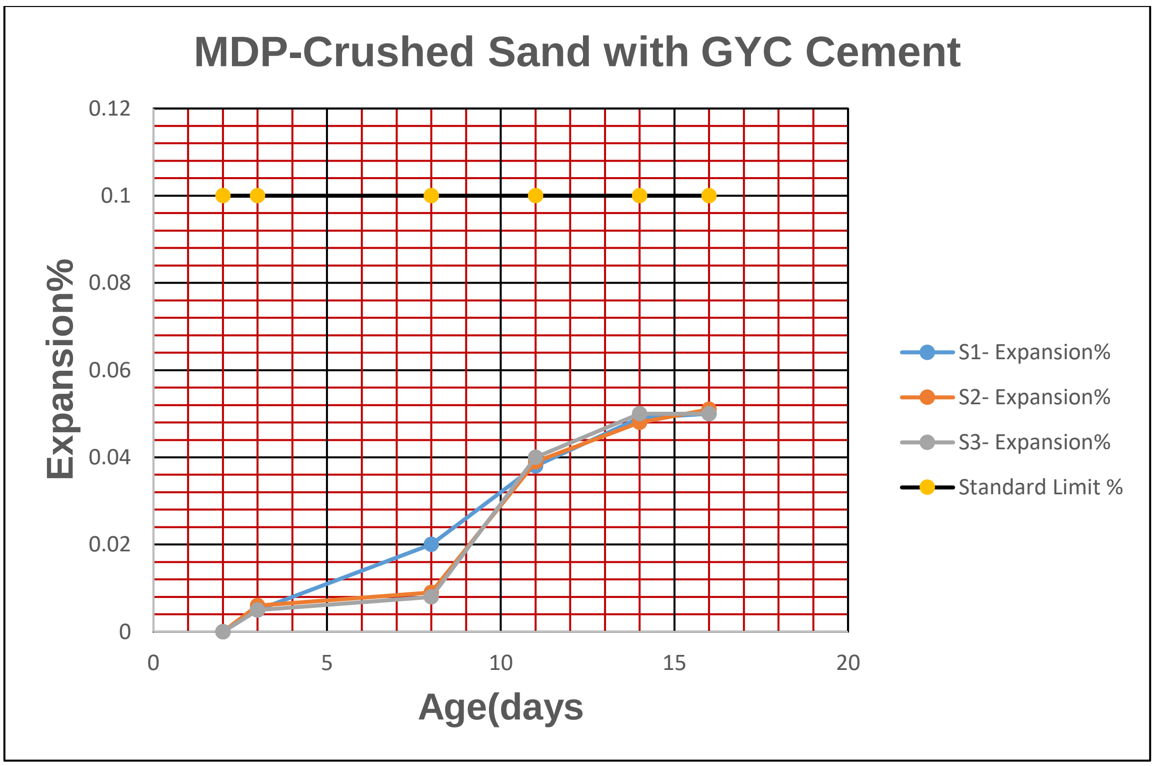

Fig3.6 Test four crushed sand mixed with GYC cement of 0.48% Na_2Oe (Merowe Dam Project Final Test Report on Concrete LI, Germany, 2009. ASTM C 1260 Accelerated Method.

3.3.2 Test Method of ASR of Aggregate used in DCUAP:

3.3.2.1 ASR Mortar-Bar Accelerated Method ASTM C 1260:

The following are the mortar bars expansion % results in 14 days

Table 3.22 Test results of five bars of crushed sand from JAQ mixed with OPC cement of 0.71 - 0.75% Na_2OE ASTM C1260 accelerated method.

	Expansion%					
T. days	M. Bar 1	M. Bar 2	M. Bar 3	M. Bar 4	M. Bar 5	Limit
0	0	0	0	0	0	0.1
1	0.002	0.001	0.001	0.001	0.001	0.1
2	0.004	0.002	0.002	0.002	0.002	0.1
3	0.009	0.003	0.005	0.005	0.005	0.1
4	0.018	0.006	0.009	0.009	0.009	0.1
5	0.027	0.015	0.015	0.016	0.015	0.1
6	0.039	0.024	0.021	0.023	0.024	0.1
7	0.048	0.033	0.032	0.033	0.032	0.1
8	0.056	0.045	0.041	0.044	0.045	0.1
9	0.065	0.054	0.050	0.054	0.055	0.1
10	0.072	0.065	0.058	0.062	0.063	0.1
11	0.077	0.072	0.067	0.069	0.070	0.1
12	0.080	0.079	0.074	0.076	0.073	0.1
13	0.083	0.083	0.076	0.078	0.075	0.1
14	0.084	0.085	0.077	0.079	0.076	0.1

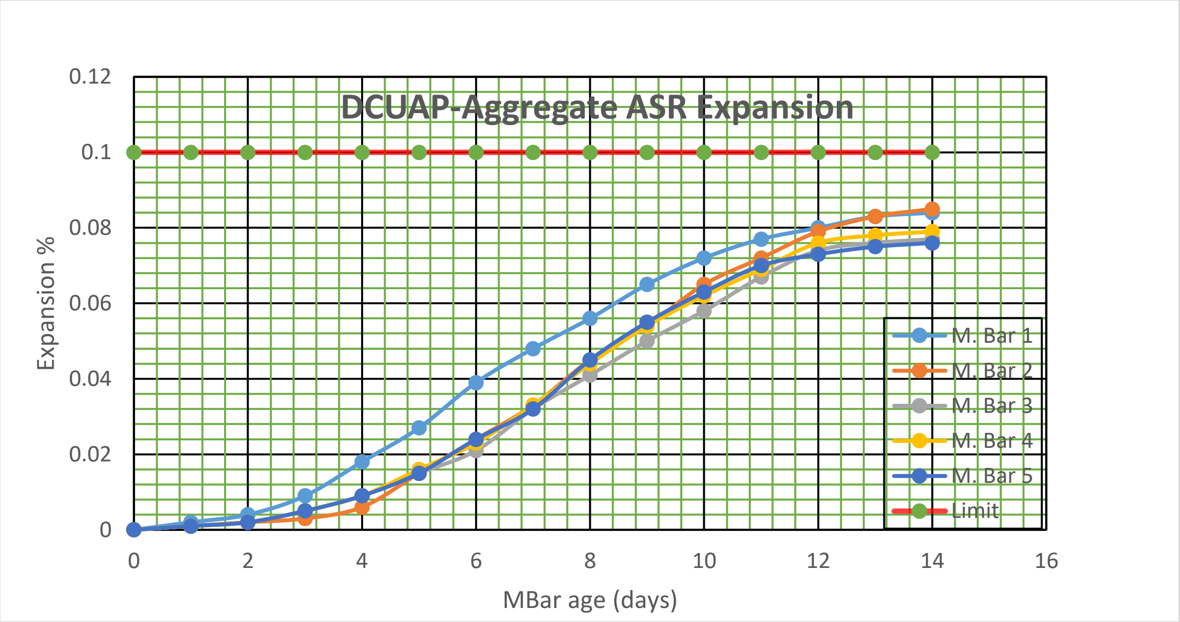

Fig 3.7 Test results of five bars of crushed sand from JAQ mixed with OPC cement of 0.71 - 0.75% Na_2OE ASTM C1260 accelerated method.

Table 3.23 Test results of six bars of crushed sand from JAQ mixed with OPC cement of 0.71 - 0.75% Na_2OE ASTM C1260 accelerated method.

	Expansion%						
T. days	M. Bar 1	M. Bar 2	M. Bar 3	M. Bar 4	M. Bar 5	M. Bar 6	Limit
0	0	0	0	0	0	0	0.1
1	0.007	0.005	0.005	0.001	0.001	0.001	0.1
2	0.011	0.008	0.008	0.002	0.002	0.002	0.1
3	0.014	0.011	0.011	0.005	0.005	0.004	0.1
4	0.018	0.015	0.015	0.008	0.008	0.010	0.1
5	0.025	0.022	0.022	0.014	0.014	0.016	0.1
6	0.031	0.027	0.027	0.020	0.021	0.022	0.1
7	0.041	0.036	0.037	0.029	0.030	0.033	0.1
8	0.048	0.045	0.046	0.040	0.042	0.043	0.1
9	0.055	0.053	0.054	0.050	0.053	0.055	0.1
10	0.060	0.058	0.057	0.057	0.059	0.062	0.1
11	0.065	0.063	0.065	0.063	0.065	0.066	0.1
12	0.068	0.066	0.067	0.070	0.072	0.068	0.1
13	0.071	0.068	0.069	0.073	0.075	0.071	0.1
14	0.073	0.070	0.071	0.074	0.076	0.073	0.1

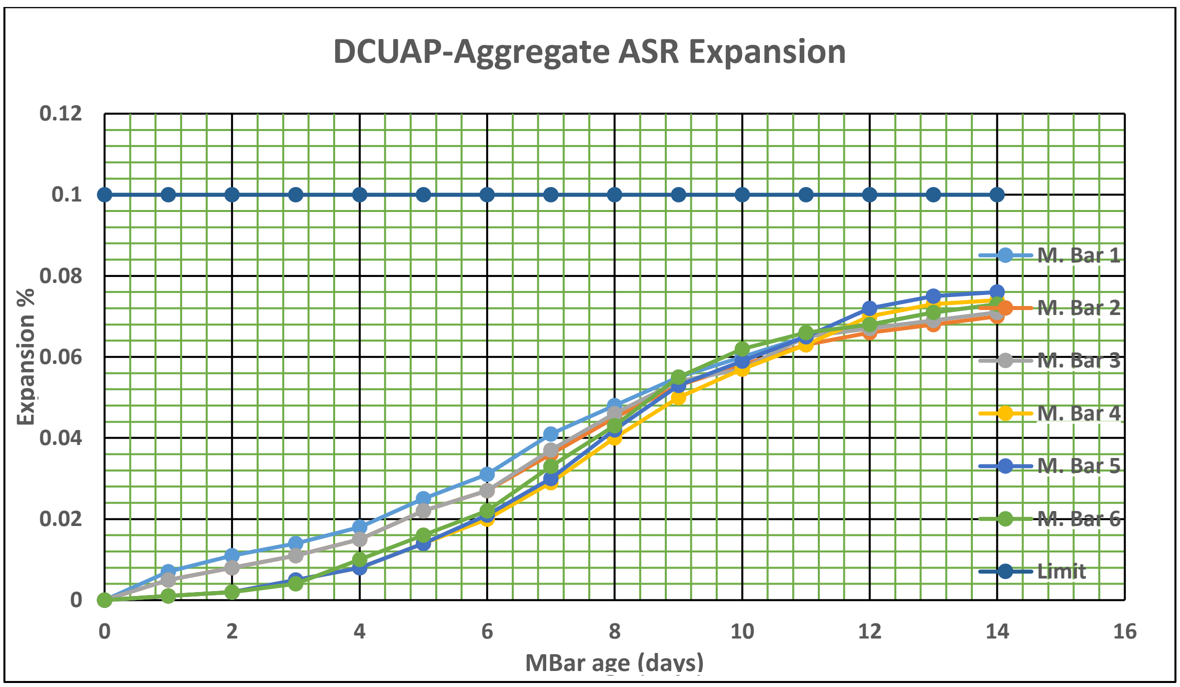

Fig 3.8 Test results of six bars of crushed sand from JAQ mixed with OPC cement of 0.71 - 0.75% Na_2OE ASTM C1260 accelerated method.

Table 3.24 Test results of seven bars of crushed sand from JAQ mixed with OPC cement of 0.71% Na_2OE ASTM C1260 accelerated method.

	Expansion%							
T. days	M. Bar 1	M. Bar 2	M. Bar 3	M. Bar 4	M. Bar 5	M. Bar 6	M. Bar 7	Limit
0	0	0	0	0	0	0	0	0.1
1	0.002	0.002	0.002	0.003	0.002	0.001	0.002	0.1
2	0.005	0.004	0.003	0.005	0.004	0.002	0.004	0.1
3	0.009	0.010	0.008	0.009	0.009	0.005	0.008	0.1
4	0.015	0.017	0.015	0.016	0.017	0.009	0.016	0.1
5	0.022	0.023	0.022	0.024	0.023	0.015	0.023	0.1
6	0.033	0.033	0.030	0.035	0.032	0.023	0.033	0.1
7	0.042	0.042	0.038	0.044	0.040	0.032	0.041	0.1
8	0.051	0.051	0.048	0.053	0.049	0.044	0.050	0.1
9	0.059	0.059	0.057	0.061	0.058	0.055	0.058	0.1
10	0.067	0.067	0.065	0.068	0.066	0.062	0.066	0.1
11	0.072	0.072	0.070	0.074	0.072	0.068	0.071	0.1
12	0.074	0.075	0.072	0.076	0.074	0.075	0.074	0.1
13	0.076	0.077	0.073	0.077	0.076	0.078	0.076	0.1
14	0.077	0.078	0.074	0.078	0.077	0.079	0.078	0.1

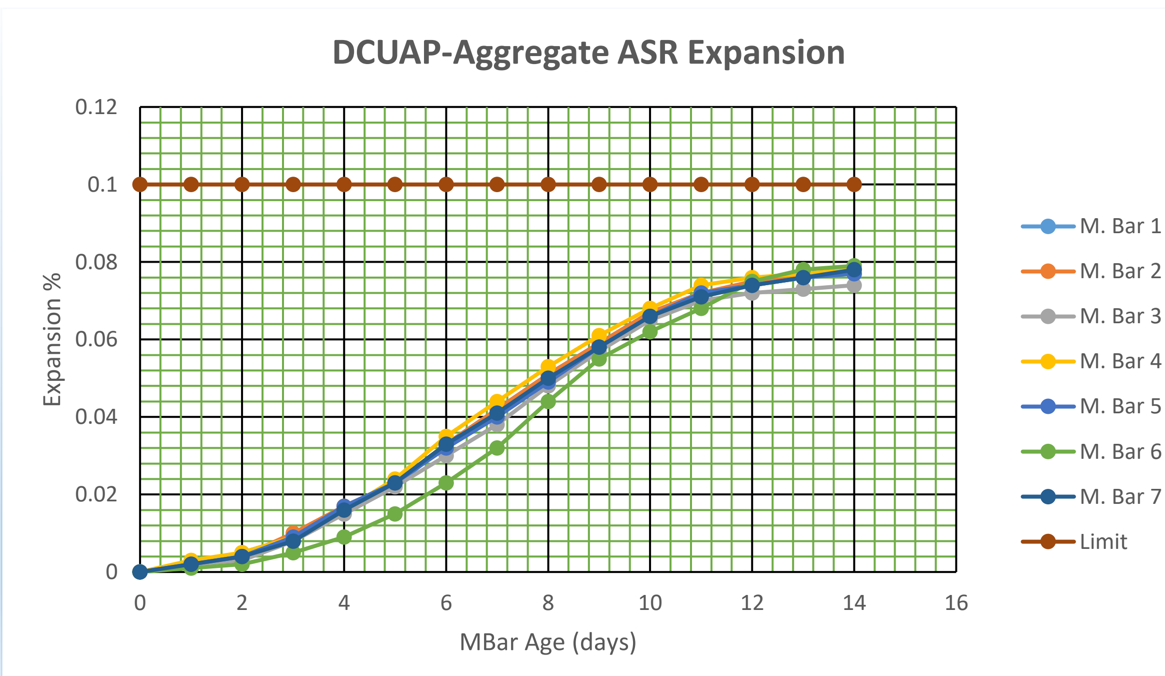

Fig3.9 Test results of seven bars of crushed sand from JAQ mixed with OPC cement of 0.71% Na_2OE ASTM C1260 accelerated method.

Table3.25 Test results of three bars of crushed sand from JAQ mixed with OPC cement of 0.75% Na_2OE ASTM C1260 accelerated method.

	Expansion%			
T. days	M. Bar 1	M. Bar 2	M. Bar 3	Limit
0	0	0	0	0.1
1	0.002	0.001	0.002	0.1
2	0.003	0.003	0.003	0.1
3	0.008	0.007	0.008	0.1
4	0.015	0.013	0.015	0.1
5	0.022	0.020	0.022	0.1
6	0.030	0.031	0.030	0.1
7	0.038	0.043	0.038	0.1
8	0.048	0.054	0.048	0.1
9	0.057	0.062	0.057	0.1
10	0.064	0.067	0.065	0.1
11	0.068	0.071	0.069	0.1
12	0.070	0.073	0.070	0.1
13	0.072	0.075	0.071	0.1
14	0.075	0.077	0.072	0.1

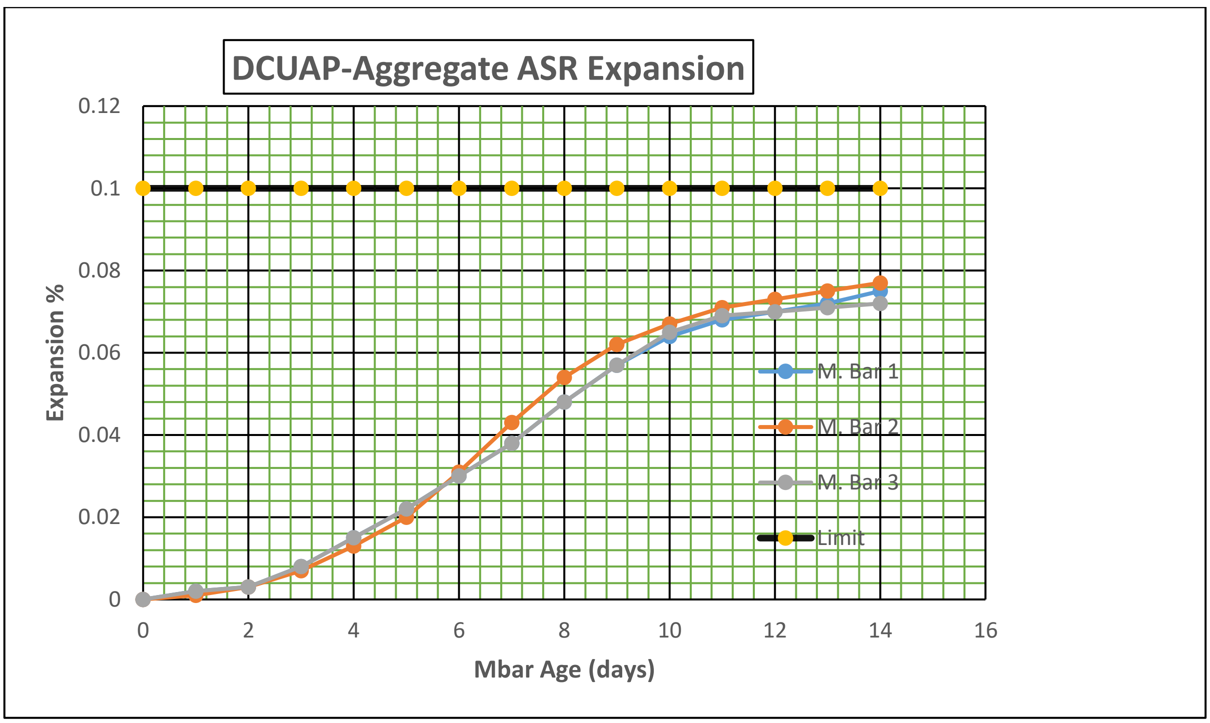

Fig3.10 Test results of three bars of crushed sand from JAQ mixed with OPC cement of 0.75% Na_2OE ASTM C1260 accelerated method.

3.4 Concrete Typical Mixes:

About 6 months prior to commencement of any concreting of permanent works, the testing of materials was started, proposed the proportion of concrete mixes and prepared the trial mixes of each of the proposed concrete class. The preliminary test program included the determination of following parameters:

a) Cement properties;
b) Characteristics of aggregates;
c) Mix water properties;
d) Admixture properties;
e) Proportion of aggregate ranges in the mix;
f) Proportion of uncrushed to crushed aggregates;
g) Cement dosage and Water-cement ratio (W/C);
h) Workability of concrete mixes and allowable slump limits;
i) Compressive and tensile strength;
j) Entrained air;
k) Density;
l) Water tightness.

The mixes for different classes of concrete have been selected in accordance to the materials and mixes properties achieved appendix C. During the progress of the work, some mixes have been changed, such change is necessary or desirable to secure the required strength, workability, water tightness, density, economy, or to limit shrinkage.

3.4.1 Concrete Typical Mix Used in MDP:

a- Mix Design No.:	MF1004,	Concrete Class:	C20/25
Aggregate Max. Size (mm):	76,	Slump (mm):	50 to 100
W/(C+P), (ACI 211):	0.50,	W/C (EN206-1):	0.59
Sand content %:	26,	Fly Ash Dosage %:	25
Admixture %:	0.9,	Wet Density kg/m^3 :	2420
Water (kg):	114,	Cement-OPC 42.5N (kg):	171
Fly Ash (kg):	56,	Crushed sand (kg):	379
Natural sand (kg):	162,	Aggregate size 19mm(kg):	461
Aggregate size 38mm(kg):	461,	Aggregate size 76mm(kg):	615

b- Mix Design No.:	MF1024,	Concrete Class:	C20/25
Aggregate Max. Size (mm):	38 ,	Slump (mm):	125 to 175
W/(C+P), (ACI 211):	0.50,	W/C (EN206-1):	0.59
Sand content %:	44,	Fly Ash Dosage %:	25
Admixture %:	0.9,	Wet Density kg/m^3 :	2361
Water (kg):	147,	Cement-OPC 42.5N (kg):	221
Fly Ash (kg):	74,	Crushed sand (kg):	589
Natural sand (kg):	252,	Aggregate size 19mm(kg):	645
Aggregate size 38mm(kg):	430		
c- Mix Design No.:	MF1020,	Concrete Class:	C30/37
Aggregate Max. Size (mm):	38 ,	Slump (mm):	175 to 225
W/(C+P), (ACI 211):	0.38,	W/C (EN206-1):	0.43
Sand content %:	44,	Fly Ash Dosage %:	22
Admixture %:	0.9,	Wet Density kg/m^3 :	2340
Water (kg):	170,	Cement-OPC 42.5N (kg):	353
Fly Ash (kg):	100,	Crushed sand (kg):	526
Natural sand (kg):	226,	Aggregate size 19mm(kg):	577
Aggregate size 38mm(kg):	384		
d- Mix Design No.:	MF1010,	Concrete Class:	C20/25
Aggregate Max. Size (mm):	19 ,	Slump (mm):	125 to 175
W/(C+P), (ACI 211):	0.50,	W/C (EN206-1):	0.59
Sand content %:	44,	Fly Ash Dosage %:	25
Admixture %:	0.9,	Wet Density kg/m^3 :	2360
Water (kg):	163,	Cement-OPC 42.5N (kg):	245
Fly Ash (kg):	81,	Crushed sand (kg):	576
Natural sand (kg):	247,	Aggregate size 19mm(kg):	1048

3.4.2 Concrete Typical Mix Used in DCUAP:

WPR: Waterproof (limited penetration depth of water)

C20/25: Compressive Strength: Cylinder 20 MPa, Cube 25 MPa

32: 32 mm maximum aggregate size (” Grade 2”)

H: High flow (pumpable)

R: Retarder added (extended workability time)

concrete unit weight: 2430 kg/m3

1. aggregates 0 - 5 mm (”sand”): 727 kg/m3

   5 - 16 mm (”grade 1”): 545 kg/m3

   16 - 32 mm (”grade 2”): 545 kg/m3

   Total 1817 kg/m3

2. cement 359 kg/m3 (42.5N slag cement)
3. water 165 l/m3
4. admixtures 3.59 kg/m3 superplasticizer

   3.59 kg/m3 retarder, diluted by 1:5

5. air typical 1 - 2 Vol. %

Table3.26: Classes of Concrete Applied in - DCUAP, Technical Specifications Contract 1 (C1-A and C1-B) Section 03000 Concrete and Reinforced Concrete.:

Concrete Class	Nominal 28-day compressive strength acc. to EN 206-1 (MN/m²)		Maximum Aggregate size (mm)	Exposure class acc. to EN 206-1	Location
	cylinder	cube			
C12/15	12	15	63	X0	Concrete gravity structures, mass and backfill concrete
C12/15	12	15	32	X0	Concrete gravity structures
C12/15	12	15	32	X0	Blinding concrete
C12/15	12	15	32	X0	Backfill & dental concrete
C12/15	12	15	16	X0	Backfill & dental concrete
C20/25	20	25	32	XC1, XC2	Reinforced concrete
C20/25	20	25	63	XC1, XC2	Reinforced concrete
C20/25	20	25	32	XC1, XC2	2nd stage concrete, with non-shrink agent
C20/25	20	25	63	XC1, XC2	Concrete used for temporary works
C20/25	20	25	32	XC1, XC2	Pre-cast concrete
C25/30	25	30	32	XC4	Reinforced concrete
C25/30	25	30	63	XC4	Reinforced concrete
C30/37	30	37	16	XC1, XC2	2nd stage concrete, with non-shrink agent
C35/45	35	45	16	XC2, XC4	Precast and pre-stressed structural concrete
C35/45	35	45	16	XC4, XM2	Reinforced concrete for vertical members exposed to considerable weir
C70/85	70	85	16	XC4, XM3	Abrasion resistant concrete

CHAPTER FOUR

RESULTS AND DISCUSSION

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction:

This chapter contains the summaries of materials tested results which include Tables and Figures illustrated in Chapter Three and compares the results to the standard requirements. The discussion of the results, will be based on the all laboratory testing results obtained from different universities, institutes and third party laboratories concerning the materials which were tested for Merowe Dam (MDP) and Dam Complex of Upper Atbara (DCUAP) Projects. Also some results were obtained from (MDP) and (DCUAP) construction's documents.

4.2 Results of Alkali contents in the cement:

The results of alkali contents in the cements used in concrete and mortar, which were used in the construction of MDP and DCUAP can be discussed as follows:

4.2.1 Alkali contents in OPC used in MDP:

The values of the alkali contents of the Marine, ECC and GYC were ranged from 0.32% to 0.59% and completely fulfilled the chemical, physical and project specification requirements according to ASTM C150 and EN 197 except one value of ECC cement reached 0.64 which is nearby the limiting value for low alkali cement (0.6%). The main source of alkalis in concrete is the alkalis in cement (Na_2O and K_2O) whose origin is the raw materials and fuel introduced into the kiln that produces the cement clinker. In modern cement plants, the raw materials are pre-heated by the hot gases leaving the upper end of the kiln. These gases contain a significant proportion of the volatile alkalis, and a part of the gases may need to be bled off to control the alkali content of the cement. This is one means of controlling the alkali content in the cement. BSEN 197 expresses the alkali content as the percentage of equivalent soda Na_2O eq [which is ($Na_2O + 0.658(K_2O)$)] in the mass of cement. Generally, three levels of alkali content in cement: low, moderate, and high are considered in a matrix with three levels of silica reactivity of aggregate: low, normal, and high as stated by: (Neville, 2006).

4.2.2 Alkali contents in GGBS Cement used in DCUAP:

The values of the alkali contents of the Ground Granulated Blast Furnace Slag cement (GGBS), nineteen tested samples with a minimum of 0.46%, maximum of 0.56% and average of 0.50%, all values fulfilled the project specification requirements according to ASTM C150 and EN 197 and lie in the level of low alkali cement.

The test results of alkali contents for both OPC used MDP and GGBS used in DCUAP, are summarized in the following Table 4.1 and illustrated in Fig 4.1

Table 4.1 Alkalis Contents in OPC and GGBS Cements

Cem. Type	Na_2Oe							
	S1	S2	S3	S4	S5	S6	S7	S8
OPC	0.32	0.32	0.42	0.43	0.59	0.58	0.48	0.64
GGBS	0.46	0.47	0.49	0.51	0.52	0.53	0.55	0.56
Limits	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60

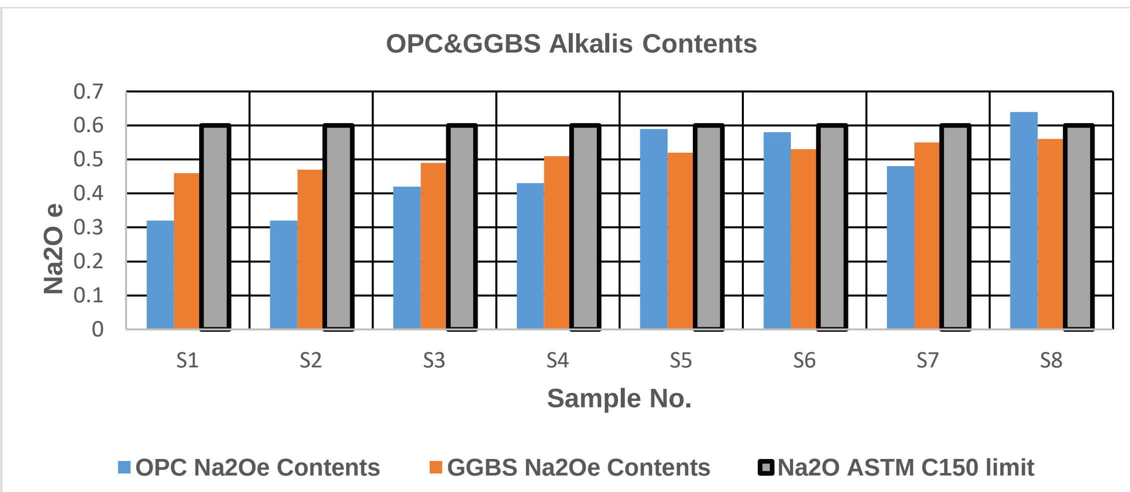

Fig. 4.1 Alkalis Contents in OPC and GGBS Cements compare to ASTM C 150 requirement.

4.3 Evaluating the potential for deleterious expansion due to ASR:

The results of the evaluating the potential for deleterious expansion due to alkali reactivity of the aggregates used in the construction of MDP and DCUAP can be discussed as follows:

4.3.1 Evaluating laboratory testing results of aggregates used in MDP:

The obtained results from Table 3.12 & Fig 3.1A plotting of the Dissolved Silica Sc and Reduction in Alkalinity Rc– chemical test method-were checked against the ASTM C289 standard evaluation curve (Fig 3.1B), all the results lie to the left of the standard evaluation curve, then the aggregate is considered to be innocuous (non-reactive), that is according to the ASTM C289 standard evaluation curve requirement: if all the results lie to the left of the curve, the aggregate is considered to be innocuous; if any of the results lie to the right of the curve, the aggregate may give rise to deleterious expansion when used in high alkali content concrete.

The four samples combined aggregate cement of high alkali content 1.21 sodium oxide equivalent as illustrated in the Table 3.14 and Fig 3.2 in Chapter Three. The cement sample of high alkali content used in the mix of mortar bar test, only for evaluation purpose of aggregate from UDQ to be used in MDP concrete whether the aggregate is reactive or nonreactive and it is not used in the production of concrete or mortar. Results from mortar bar test ASTM C 227 running for 90 days, were found; sample one 0.034%, sample two 0.042%, sample three 0.040% and sample four 0.036%, revealed that all of the aggregate samples tested gave expansions less than the ASTM C 33 stated not more than 0.050% in 3 months. Therefore, the aggregate considered as innocuous – non-reactive.

The results of the powdered material of the sand sample was analyzed by x-ray diffraction. Calibration curves from the essential rock forming minerals permit semi-quantitative mineral analysis as in Chapter Three Table 3.16. There are no obvious differences in the minerals composition of the different sand samples in the XRD spectra visible.

The results obtained from ASTM C1260 Accelerated Mortar Bar Test (AMBT) in 16 days as summarized from Chapter Three (Figures 3.3, 3.4, 3.5 and 3.6) and illustrated in Fig 4.2 below, are less than the maximum limit expansion stated by the standard expansion% limit in 16 days (0.1%). Therefore, the aggregates both Natural Sand (NS) and Crushed Sand (CS) from Wadi Abu Sibba and UDQ sources MDP, considered as innocuous – non-reactive.

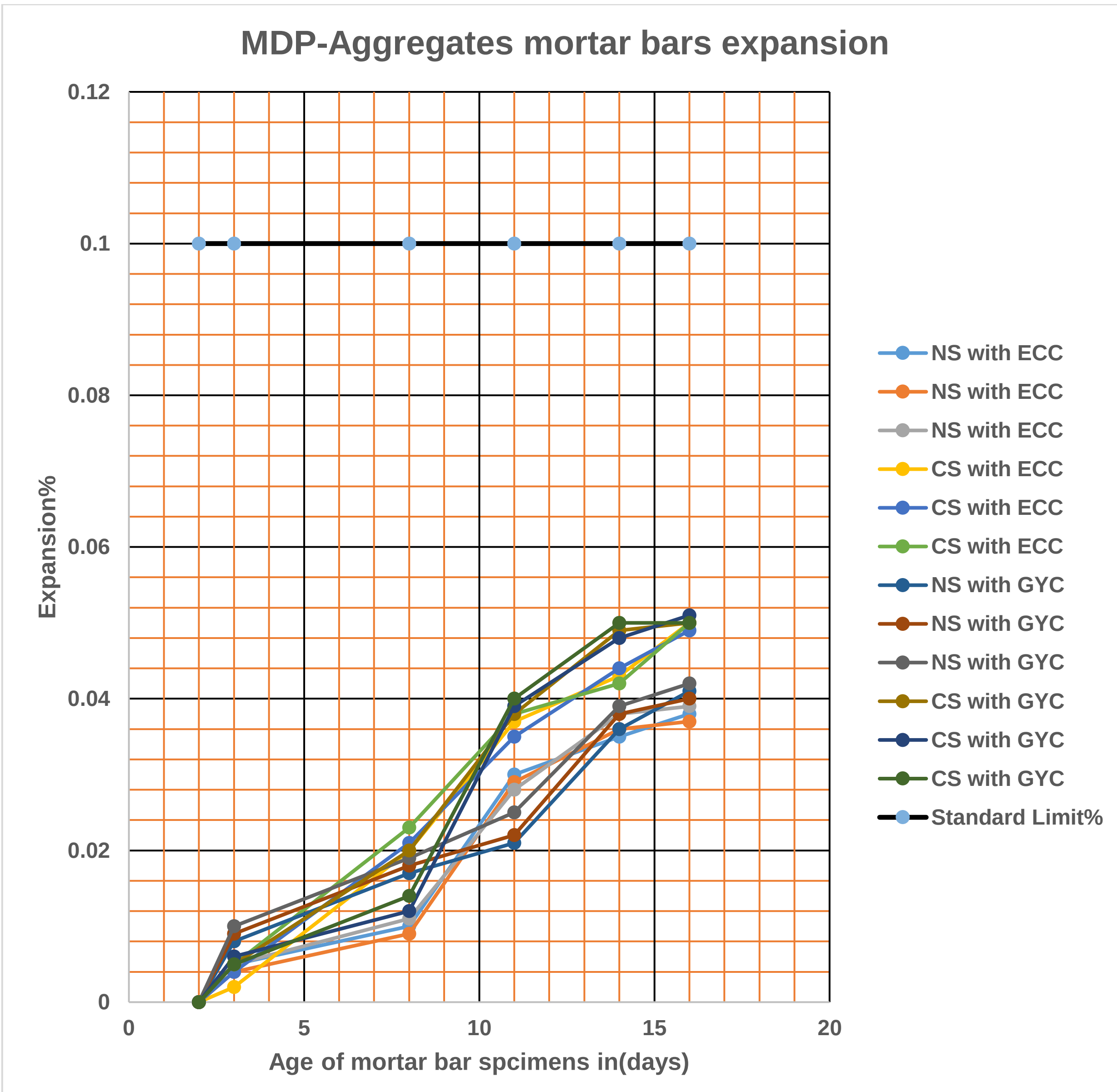

Fig 4.2 Expansion of mortar bars made with Crushed Sand (CS) UDQ source, Natural Sand(NS) Abu Sibba source and ECC & GYC - ASTM C 1260 Accelerated Method.

4.3.2 Evaluating laboratory testing results of aggregates used in DCUAP:

The results obtained from ASTM C1260 accelerated mortar bar test method in 16 days from casting combined aggregate from Jebel Aklaiyit Quarry (JAQ) and OPC cement of 0.71 to 0.75% Na_2OE used for evaluation purpose of aggregate running in period 2013 to 2017 as summarized from Chapter Three (Figures: 3.7, 3.8, 3.9 & 3.10) and illustrated in Fig 4.3 below, are less than the maximum limit expansion stated by the ASTM standard (0. 1%). Twenty-one (21) mortar bar samples results, minimum expansion 0.070%, maximum expansion 0.085% and average expansion 0.076%. Therefore, the aggregates from JAQ source are considered as innocuous – non-reactive aggregates.

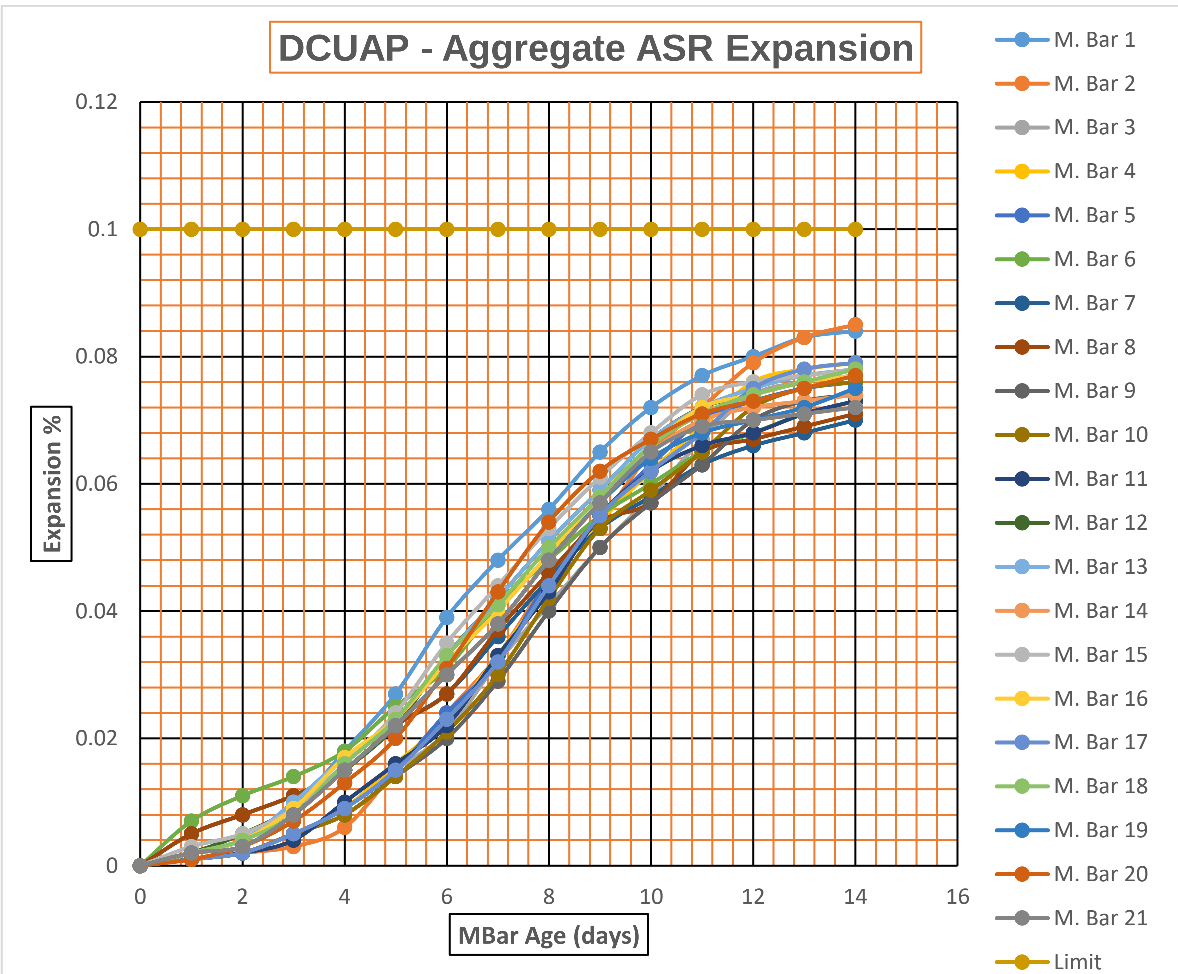

Fig4.3: Expansion of mortar bars from aggregate JAQ source and OPC cement of 0.71 to 0.75% Na_2OE ASTM C 1260 Accelerated Method (time:2013 to 2017)

4.4 Fly Ash and Natural Pozzolan:

Chemical and physical properties of Fly Ash Type F (ASTM C618) imported from China and tested by supplier as well as the third party Laboratories. The results as stated in Chapter Three Table: 3.7 chemical and physical properties of Fly Ash Type F, Table 3.8 Fly ash class F chemical properties, Table 3.9 Fly ash class F Physical properties, Table 3.10 Natural Pozzolan test results of compressive strength and Table 3.11 chemical properties of Natural Pozzolan. The Fly Ash Type F samples tested for chemical and physical properties, are conforming to ASTM C618 and ASTM C311. In MDP, the Fly Ash Type F is used in the production of concrete and mortar to replace the cement in mix design by 25% expressed by weight

The testing results of Local Natural Pozzolan are not fulfilled the standard requirements, therefore, the local natural pozzolan was not used in the concrete works for MDP or DCUAP.

4.5 Concrete Typical Mixes Used:

In MDP, although all the tested aggregate from UDQ source have been found innocuous nonreactive aggregate, but the parties of the project agreed to use the supplementary cementitious material (SCM) Fly Ash to replace 25% of the cement used in concrete mixes not only for Alkali-Silica Reactivity mitigation reason, but also for reducing heat of hydration, as a filler to reduce seepage, to increase workability of concrete and as a benefit by reducing the cost of concrete production per cubic meter, because the price of fly ash was less than the price of the cement, about 90$ per ton for Fly Ash and 110$ per ton for Ordinary Portland GYC (saving 20$ per ton of cement to be used in concrete production). The Egyptian cement ECC in Table 3.5 appeared and shown in Table 4.1 as OPC sample S_8 with alkali content 0.64% Na2Oe which is nearby and a little more than the ASTM C 150 standard requirement 0.60%. This cement sample was combined and mixed with aggregate from UDQ and Wadi Abu Sibba sources in MDP and tested for AMBT, the results in Chapter Three Table 3.18 and Table 3.19 showing expansion in 16 days 0.039% and 0.050% respectively. Therefore, the results are less expansion than the ASTM C 1260 expansion requirement in 16 days not more than 0.01%. In addition to the expansion measurements results, the use of the Supplementary Cementitious Materials (SCM) Fly Ash Type F 25% to replace cement in the concrete production, considered to mitigate ASR and hence, the alkali content 0.64% of the Egyptian cement ECC S_8, did not affect the concrete from mitigation and protection of alkali silica reactivity deleterious in MDP.

In DCUAP, the testing results of aggregate from JAQ source have been found innocuous nonreactive aggregate. Two proposal of concrete mixes have been set out:

. No.1 Mix of concrete using OPC and replace 25% by Fly Ash Type F, or

. No.2 Mix of concrete using GGBS without replacing by Fly Ash

The parties of the project agreed to use proposal No.2 using mixes of GGBS without replacing by Fly Ash. No further filler (fly-ash) needed, low heat of hydration dense concrete (less pores) GGBS cement showed superior performance for chloride and sulfate attack resistance.

4.6 Research results comparison:

Comparison of the testing results for this research, to some previous studies for mitigating ASR, can be summarized in the following Table:

Table 4.2 Research Comparison results

No.	This Research	Previous Studies
1	OPC alkali contents Na_2Oe up to 0.64%	OPC alkali contents Na_2Oe up to 0.64%
2	Using nonreactive aggregates, expansion not more than 0.05% (Table 3.21) in 16 days.	Using reactive, nonreactive and Soda lime glass as coarse aggregates with SCM.
3	Using Fly Ash Class F 25% as SCM.	Using Fly ash Class F and Class C 15%, 20 – 30% and 25% as SCM.
4	Using Ground Granulated Blast Furnace Slag (GGBS), 30%OPC and 70%GGBS.	Using GGBS with dosage, 50% and 70% as SCM.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

In this chapter, all the laboratory testing results which have been discussed in Chapter Four will be concluded as the research findings also recommendations for future studies will be stated.

5.2 Conclusion

The scope of this research is to test and select the materials proposed to be used in concrete and mortar for the new construction of MDP & DCUAP Projects whether the materials fulfill or not the stated project technical specifications and international standard requirements for mitigating alkali silica reaction in concrete and mortar for hydropower structures.

The cements; OPC and GGBS used in both projects, was of low level alkali content, less than 0.6% of Na_2O equivalent and the crushed and natural aggregates; combined with moderate and high levels of alkali content cement for expansion test, was of low level reactive aggregates (innocuous).

Based on the laboratory testing methods, performed in different Universities and Institutes and the results obtained concerning alkali silica reaction for fine and coarse aggregates used in concrete and mortar production for construction of MDP & DCUAP projects, all the results fulfilled and verified the standard requirements and limits stated for mitigating alkali content in the cement material and the siliceous found in the aggregates materials, therefore, the concrete and mortar produced from such materials were mitigated from deleterious expansion and damage due to alkali silica reaction.

Using of supplementary cementitious material (SCM) Fly Ash to replace 25% of the cement used in concrete mixes not only for minimizing risk of any probable Alkali-Silica Reactivity mitigation reason, but also for reducing heat of hydration, as a filler to reduce seepage, to increase workability of concrete and as a benefit by reducing the cost of concrete production per cubic meter.

It is obvious, from the testing results obtained; to mitigate alkali silica reactivity; there are two options: combine innocuous aggregate with even high level alkali content cement will fulfill the standard requirements for mitigating ASR or combine reactive natural sand with low level alkali content, also will mitigate ASR.

5.3 Recommendations:

- Prior to any construction of concrete, which may be exposed to wetting during service operation, the cement and aggregates materials proposed to be utilized, shall be checked and tested against alkali aggregate reaction.
- Attention shall be paid to the visual inspection of existing concrete structures of dams, bridges, water tanks and similar concrete structures which were exposed to wetting environment, the cracks and other signs of concrete deteriorations and compared them to those listed signs caused by alkali aggregate reaction to take early measures for remedial.
- It is required to establish service record for Sudanese aggregates quarries which have been used in concrete production for dams, bridges and similar concrete constructed from the same aggregate quarries.
- The testing results of local natural pozzolan from Buyda desert central volcanic field, mainly from Abu Serjain mountain, 6 km West of Bir Sani. Although the results are not fulfilling the standard specification of natural pozzolan according to ASTM C618, but more efforts required to be paid concerning the ASTM C618 and ASTM C311 requirements, that is for beneficial of replacing the cement as supplementary cementitious materials using in concrete mixes for mitigation of alkali silica reaction.

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Appendices:

Appendix A: Request Acceptance and Author related CV.

التاريـــخ: 2021/12/12م

السيد/ المدير العام لوحدة تنفيذ السدود

لعناية/ م. محمد نورالدين

تحية طيبة

الموضوع : طلب إذن لإستخدام النتائج المختبرية

بالإشارة إلي الموضوع أعلاه نرجو شاكرين السماح والموافقة لنا بإستخدام بعض النتائج المختبرية الخاصة بتفاعل قلويات الأسمنت مع السليكات بالحصي المستخدم في الخرسانات بمشاريع سد مروي وسدي أعالي عطبرة وستيت ومياه القضارف وذلك لغرض البحث التكميلي لنيل درجة الماجستير بعنوان " تقليل تفاعل القلويات مع السليكات بإستخدام الرماد المتطاير وأسمنت الخبث في المنشآت الخرسانات المائية " بجامعة السودان للعلوم والتكنولوجيا.

مع وافر شكرنا وتقديرنا

12/12/2021

الطالب/ عبد الحنان عمر إبراهيم

المشرف/ د. مشاعر عبد الرحيم

13 DEC 2021

وزارة الرى والموارد المائية

وحدة تنفيذ السدود

الادارة العامة للموارد البشرية والمالية والادارية

إستمارة توجية ومتابعة

التاريخ	2021/12/14	رقم الخطاب		رقم الإستمارة	1738
المرسل	مكتب المدير العام				
الموضوع	طلب إذن لإستخدام النتائج المختبرية				

	الإدارات المتخصصة	للإجراء	للمراجعة	للإفادة	للتشاور	للمتابعة	للعلم	للحفظ
.1	مدير إدارة المراجعة الداخلية							
.2	مدير إدارة الشئون المالية							
.3	مدير إدارة الشئون الإدارية							
.4	مدير إدارة الموارد البشرية والتدريب							
.5	مدير إدارة المعلومات والتقنية							
.6	مدير التشغيل والصيانة							
.7	مدير صندوق تكافل العاملين							
.8	رئيس لجنة المشتروات							
.9	مدير المكتب التنفيذي							

توجيه/ تعليق إضـــــافي:

التوقيع:-

التاريخ:- 2021.12.14

الرد أو الإفادة خلال:

عاجل	24 ساعة	48 ساعة	اسبوع

ملحوظة: يضطلع المكتب التنفيذى بالمتابعة والرد خلال الفترة المحددة

وزارة الري و الموارد المائية
Ministry of Irrigation & Water Resources

وحدة تنفيذ السدود
Dams Implementation Unit

مكتب المدير العام –مذكرة داخلية

التاريخ : 13/ 12 / 2021م .... الرقم المتسلسل : (576 / 2021) ....

الجهة المرسلة: عبدالحنان عمر ابراهيم

الموضوع: طلب اذن لاستخدام النتائج المختبرية

م	الإدارات العامة	للإجراء	للمراجعة	للإفادة	للتشاور	للعلم	للمتابعة	للحفظ	عاجل
1	الادارة العامة للموارد البشرية والمالية والادارية	✓							
2	الادارة العامة للتخطيط والمشروعات والبيئة	✓							
3	الادارة العامة لحصاد المياه								
4	مفوضية الشئون الاجتماعية								
5	المستشار القانوني								
6	مدير إدارة التامين								
7	مدير إدارة المراجعة الداخلية								
8	مدير المكتب التنفيذي	✓							

توجيه أو تعليق إضافي :-

التنفيذي للمتابعة

التوقيع: ....

التاريخ: 12/12

وحدة تنفيذ السدود
الإدارة العامة للموارد البشرية والمالية والإدارية
14 DEC 2021
المكتب التنفيذي

Author Curriculum Vitae (CV.)

Abdelhannan Omer Ibrahim Shamsadeen

Birth, 1963 Algeneina - Kungy Village, West Darfur, living in Wad Madani & Khartoum North.

Civil Engineer and Quality Professional.

- Education:

- MSc. Student in Civil Engineering – Construction Management, SUST, 2018.
- BSc. In Civil Engineering Hydraulics, SUST, Nov. 2015.
- Diploma in Civil Engineering Highway, KP, Oct. 1989

- Work Experiences & Construction Supervision Teams:

- Technical Office & Administrative Affairs Manager, Dams Implementation Unit (DIU) - Ministry of Irrigation and Water Resources, 2016 to date.
- Senior QC Concrete Engineer, Lahmeyer International, Dam Complex of Upper Atbara Project (DCUAP), 2011 – 2016.
- Senior Laboratory Engineer, Lahmeyer International, Merowe Dam Project, (MDP) 2004 – 2010.

Appendix B: Photos

Photo B-1, Thomas Stanton of the California State Division of Highways and a Bridge Parapet Wall that is Showing Signs of Damage due to Alkali-Silica Reaction.

Photo B-2, The Nant-y-Moch Dam in 2011 – No Symptoms of ASR after 50 Years – Constructed with Reactive Aggregate and 25% Fly Ash, United Kingdom, Wales.

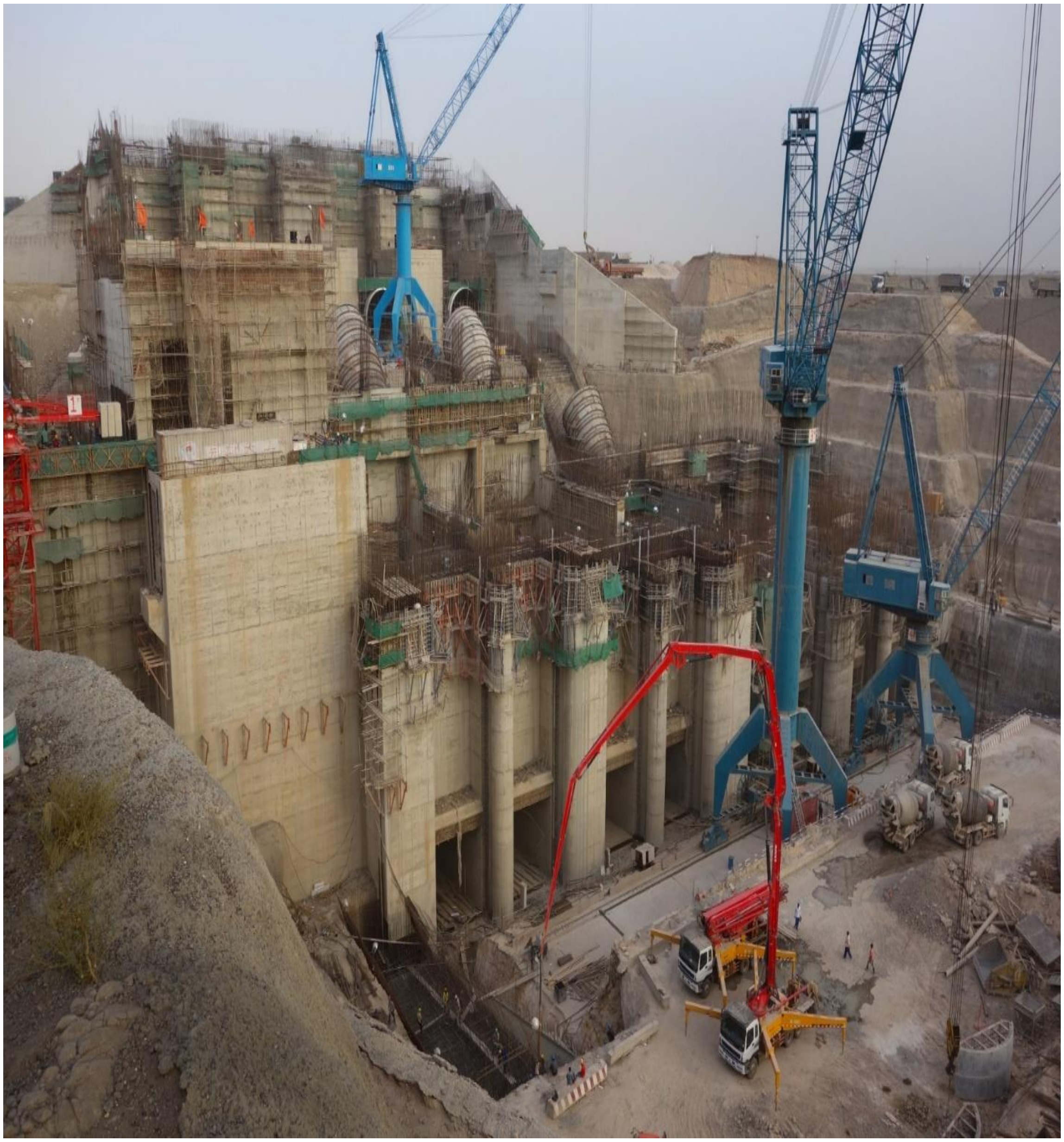

Photo B-3, DCUAP- Down Stream Power Station Concreting.

Photo B-4, Merowe Dam Project(MDP) – Start Preparation for Concreting.

Merowe Dam MDP
Irrigation / Hydropower

2004 – 2010
1250 MW
2 Billion €
Contractors CCMD-JV / Alstom

Dam Complex of Upper Atbara DCUAP
Irrigation / Hydropower / Water Supply

2010 – 2017
320 MW
1 Billion €
Contractors CWE-CTGC JV / Harbin

Photo B-5, MDP & DCUAP

Merowe Dam Project (MDP)- Challenges

remote location	distance to Port Sudan 1000 km
climate	up to 50 °C
2 040 000 m^3	concrete (max. 66 000 m^3 / month)
530 000 t	portland cement (max. 600 tons / day)
126 000 t	reinforcement steel
22 000 000 m^3	excavation / embankment
$>$ 1 000 000 l	diesel per month
$>$ 600	vehicles running
up to 6500	people
communication	by mobile phones
€2 billions	approx. total project costs

Photo B-6, MDP challenges

Dam Complex of Upper Atbara Project (DCUAP):

MAIN DATA

- *Total 11.3 Mm^3 common and rock excavation*
- *11.9 Mm^3 fill*
- *Zoned earth fill embankment dam for the two river sections of up to 55 m height*
- *Homogeneous type of embankment dams with maximum 25 m height*
- *Total length of the embankment dam of about 13 km*
- *7,900 m^2 plastic concrete of two cut-off walls crossing the riverbeds of Setit and Atbara*
- *61,000 m^2 of mixed in place cut-off walls in the Setit river banks*
- *950,000 m^3 concrete*

- *Total storage volume 3.7 billion m^3 at full supply level*
- *Active storage volume 2.5 billion m^3*
- *Two Spillways, maximum discharges 5,300 m^3/s and 9,800 m^3/s*
- *Maximum gross head 38.85 m*
- *4 x 80 MW Kaplan Turbines, 320 MW total*

Total project cost approximately 1.0 Billion USD

Photo B-7, DCUAP main data

Photo B-8, A petrographic microscope instrument

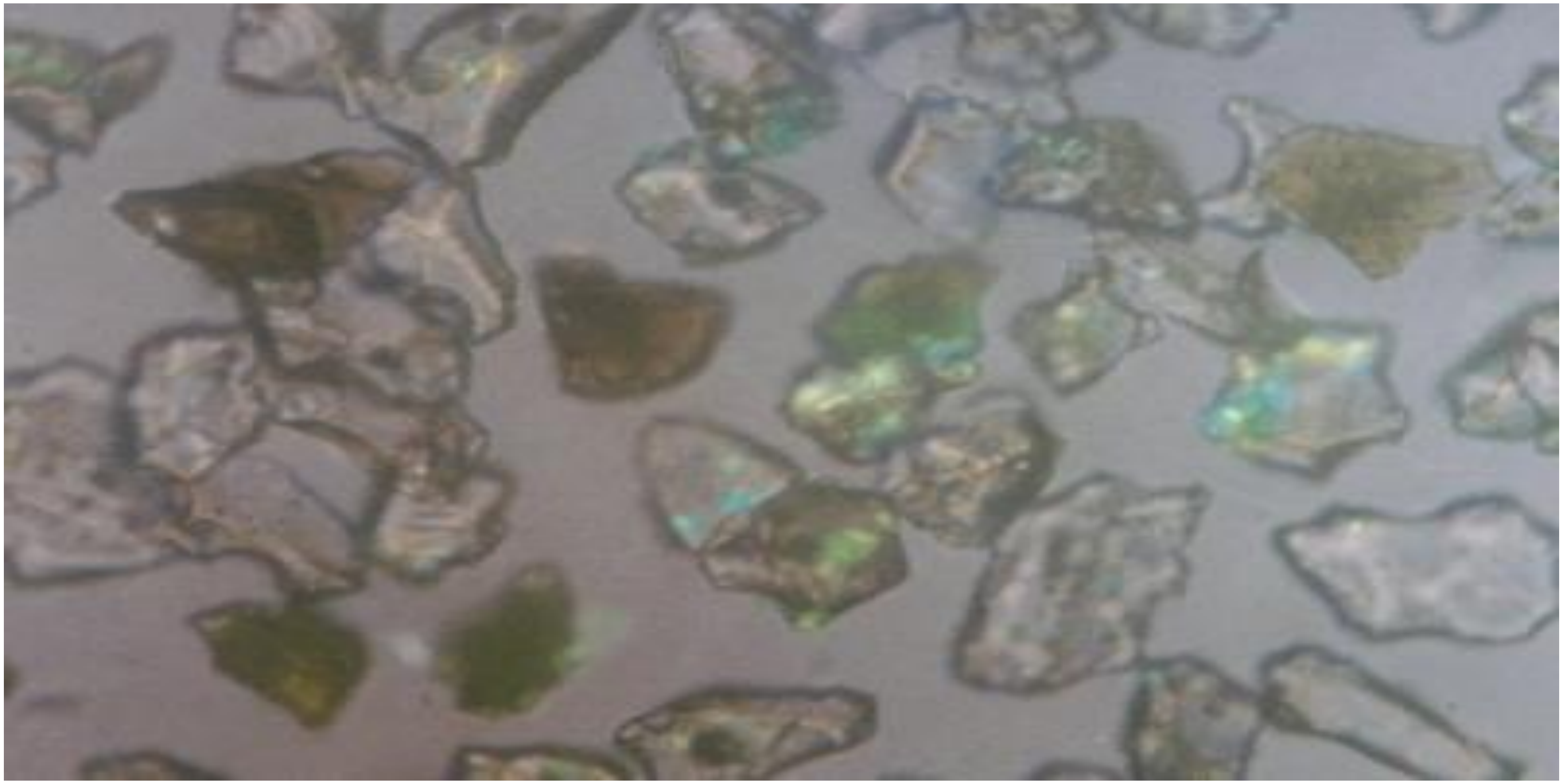

Photo B-9, GGBS Cement (10 microns)

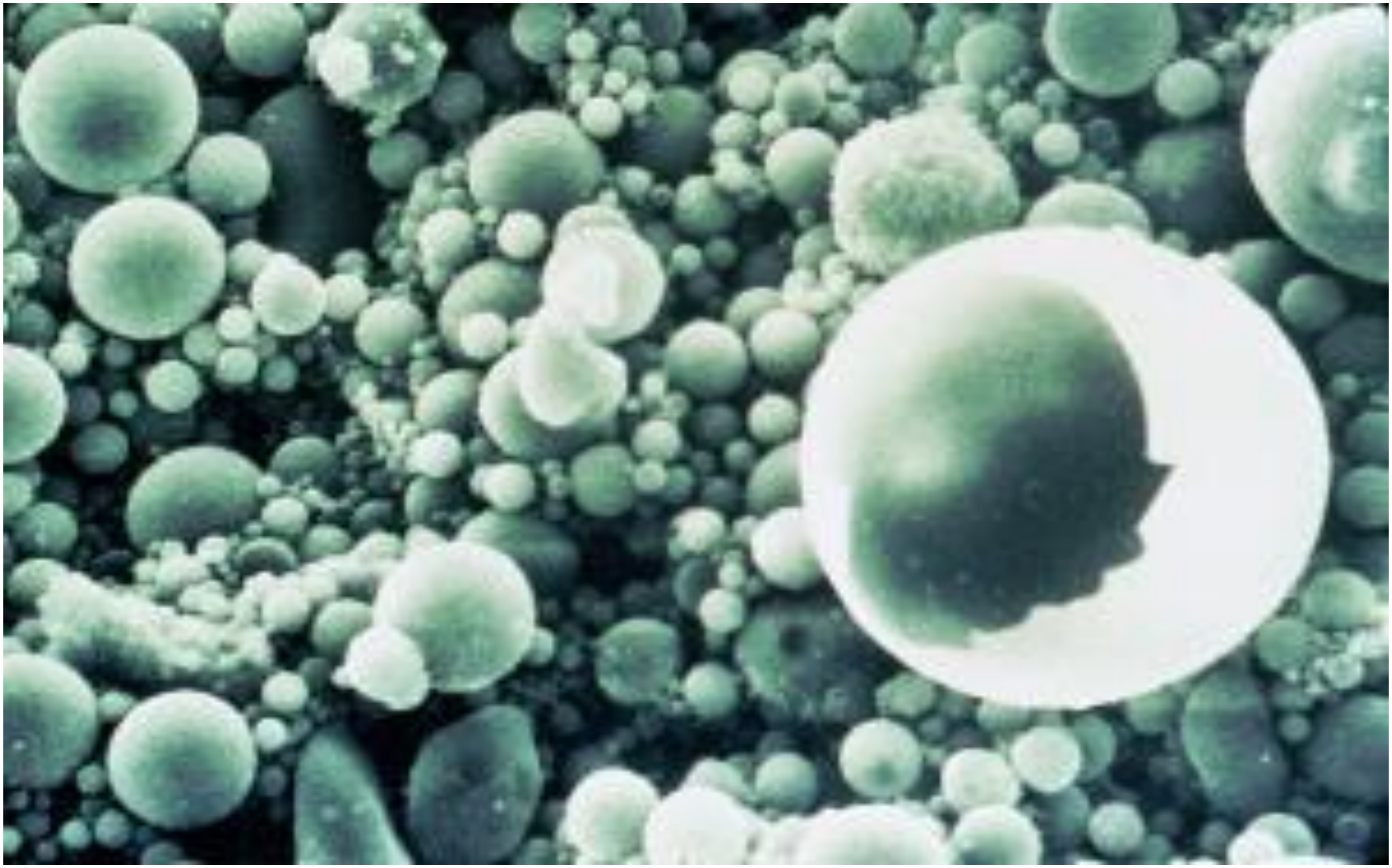

Photo B-10, Fly Ash (10 microns)

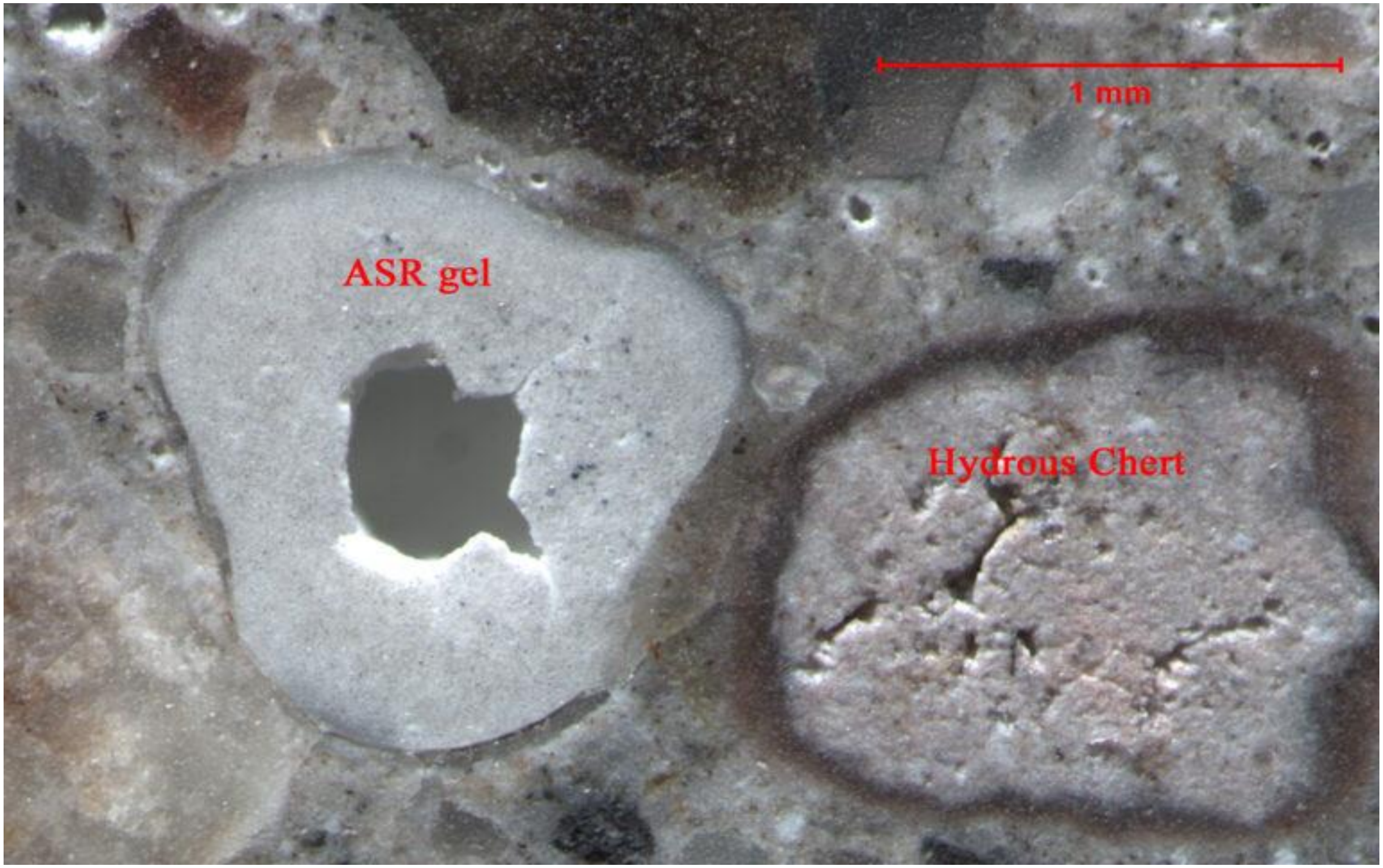

Photo B-11 (ASR) remains a major durability issue affecting concrete structures, including heavy civil infrastructure, such as dams, bridges and pavements

Appendix C: Typical Mix Designs

Actual Concrete Mix Design (07/07/2007)

MIX Design NO.	Concrete Classes	Aggregate Max.Size (mm)	Design Slump (cm)	W/(C+P) (ACI 211)	W/C (EN206-1)	Sand Content (%)	Fly Ash Dosage	Nonshrink Dosage	Admixture Dosage (ZB-1)	Wet Density (kg/m3)	Concrete material consumption per cubic meter (kg)												Remark
											W	C	F	Nonshrink	Crushed sand	Natural sand	Coarse Aggregate-Max.Size (mm)					Admixture (ZB-1)	
																	10mm	19mm	38mm	76mm	120mm		
	2B-SPILLWAY,Non-Overflow,Power House,Apron; 2A,2C-Plinth,Leveling,Dental and Cap Concrete																						
MF1001	C12/15	120	5 to 10	0.65	0.76	24	25%	0%	0.9%	2440	102	118	39	0	366	157	0	332	332	497	497	1.413	
MF1002	C12/15	76	5 to 10	0.65	0.76	29	25%	0%	0.9%	2420	114	132	44	0	433	185	0	454	454	605		1.584	
MF1003	C12/15	38	5 to 10	0.70	0.83	36	25%	0%	0.9%	2390	132	141	47	0	522	224	0	530	795			1.692	
MF1027	C12/15	19	12.5 to 17.5	0.65	0.76	45	25%	0%	0.9%	2360	162	187	62	0	614	263	0	1072				2.241	pumpable
MF1004	C20/25	76	5 to 10	0.50	0.59	26	25%	0%	0.9%	2420	114	171	56	0	379	162	0	461	461	615		2.043	Mass concrete
MF1005	C20/25	76	12.5 to 17.5	0.50	0.59	32	25%	0%	0.9%	2390	140	210	69	0	442	189	0	536	469	335		2.511	Reinforce concrete
MF1006	C20/25	38	5 to 10	0.50	0.59	33	25%	0%	0.9%	2390	130	195	64	0	462	198	0	536	805			2.331	Reinforce concrete
MF1024	C20/25	38	12.5 to 17.5	0.50	0.59	44	25%	0%	0.9%	2361	147	221	74	0	589	252	0	645	430			2.655	Pumpable
MF1026	C20/25	38	12.5 to 17.5	0.49	0.56	44	20%	0%	0.9%	2366	147	240	60	0	589	252	0	645	430			2.700	Pumpable, for concrete exposed to wet-dry Zones
MF1025	C20/25	38	17.5 to 22.5	0.50	0.59	45	25%	0%	0.9%	2340	160	240	80	0	584	250	0	614	409			2.880	Pumpable
MF1009	C20/25	19	5 to 10	0.50	0.59	36.5	25%	0%	0.9%	2360	152	228	75	0	487	209	0	1210				2.727	
MF1010	C20/25	19	12.5 to 17.5	0.50	0.59	44	25%	0%	0.9%	2360	163	245	81	0	576	247	0	1048				2.934	pumpable
MF1011	C20/25	19	17.5 to 22.5	0.50	0.59	45	25%	0%	0.9%	2360	185	278	92	0	568	244	0	993				3.330	pumpable
MF1012	C30/37	76	5 to 10	0.37	0.44	26	25%	0%	0.9%	2420	125	253	83	0	356	153	0	435	435	579		3.024	
MF1013	C30/37	38	5 to 10	0.37	0.44	32.5	25%	0%	0.9%	2390	135	274	90	0	431	185	0	511	765			3.276	
MF1014	C30/37	38	12.5 to 17.5	0.37	0.44	40	25%	0%	0.9%	2390	160	324	107	0	504	216	0	648	431			3.879	pumpable
MF1020	C30/37	38	17.5 to 22.5	0.38	0.43	44	22%	0%	0.9%	2340	170	353	100	0	526	226	0	577	384			4.077	pumpable
MF1016	C30/37	19	5 to 10	0.37	0.44	35	25%	0%	0.9%	2360	160	324	107	0	433	186	0	1150				3.879	
MF1022	C30/37	19	12.5 to 17.5	0.38	0.43	43	21%	0%	0.9%	2340	171	357	95	0	515	221	0	978				4.068	pumpable
MF1023	C30/37	19	17.5 to 22.5	0.38	0.43	44	20%	0%	0.9%	2317	188	395	99	0	501	215	0	915				4.446	pumpable
MF2001	C20/25	38	5 to 10	0.50	0.59	33	25%	0%	0.5%	2390	132	198	65	0	461	197	0	535	802			1.315	
MF2018	C20/25	38	12.5 to 17.5	0.50	0.59	44	25%	0%	0.5%	2344	157	236	79	0	575	246	0	629	420			1.575	pumpable
MF2019	C20/25	38	17.5 to 22.5	0.50	0.59	45	25%	0%	0.5%	2325	170	255	85	0	570	244	0	599	400			1.700	pumpable
MF2004	C20/25	19	5 to 10	0.50	0.59	36.5	25%	0%	0.5%	2360	155	233	77	0	484	208	0	1203				1.550	
MF2005	C20/25	19	12.5 to 17.5	0.50	0.59	44	25%	0%	0.5%	2360	168	252	83	0	572	245	0	1040				1.675	pumpable
MF2006	C20/25	19	17.5 to 22.5	0.50	0.59	44	25%	0%	0.5%	2360	185	278	92	0	556	238	0	1011				1.850	pumpable
MF2007	C30/37	38	5 to 10	0.37	0.44	32.5	25%	0%	0.5%	2390	140	284	94	0	426	182	0	506	758			1.890	
MF2013	C30/37	38	12.5 to 17.5	0.36	0.41	43	21%	0%	0.5%	2350	163	355	96	0	521	223	0	594	396			2.255	pumpable
MF2014	C30/37	38	17.5 to 22.5	0.38	0.43	44	21%	0%	0.5%	2329	178	371	99	0	516	221	0	565	377			2.350	pumpable
MF2015	C30/37	19	5 to 10	0.37	0.43	35	23%	0%	0.5%	2352	160	332	99	0	430	184	0	1145				2.155	
MF2016	C30/37	19	12.5 to 17.5	0.38	0.43	43	21%	0%	0.5%	2333	175	365	97	0	509	218	0	967				2.310	pumpable
MF2017	C30/37	19	17.5 to 22.5	0.38	0.43	44	20%	0%	0.5%	2315	188	395	99	0	501	215	0	915				2.470	pumpable
	2A,2C-Sliding Formwork Concrete																						
MF3001	C20/25	38	2.5 to 7.5	0.50	0.55	36	15%	0%	0.0%	2390	167	284	50	0	476	204	0	605	605			0.000	
MF3002	C20/25	19	5 to 10	0.50	0.55	45	15%	0%	0.0%	2299	185	315	56	0	549	235	0	959				0.000	
	Pre-cast concrete																						
MF4001	C20/25	19	10 to 15	0.50	0.50	45	0%	0%	0.5%	2344	186	372	0	0	563	241	0	982				1.860	
MF4002	C30/37	19	10 to 15	0.42	0.42	45	0%	0%	0.5%	2344	189	450	0	0	537	230	0	938				2.250	
	2nd Stage Concrete with Nonshrink Agent																						
NS003	C30/37	19	17.5 to 22.5	0.39	0.43	46.5	13.0%	7%	0.5%	2325	190	420	63	29.4	0	752	0	868				2.415	
	Concrete for Grouting																						
MF7001.A	C30/37	10	10 to 28	0.43	0.45	50	8%	7%	0.8%	2401	249	530	45	37.1	770	0	770	0	0	0	0	4.240	The slump range is about 100~280mm,depending on site work.
	Flowing Concrete Mix Design																						
NS001	C20/25	19	20 to 28	0.40	0.43	46.5	13%	0%	0.9%	2234	190	420	60	0.0	0	725	0	835	0	0	0	3.800	
NS002	C20/25	19	15 to 28	0.40	0.43	46.5	13%	7%	0.9%	2259	190	420	60	29.4	0	725	0	835	0	0	0	3.800	

Accepted
20.07.07

CCMD JV Laboratory
2007.07.07