THE PRELIMINARY EVALUATION OF THE SUSCEPTIBILITY OF CYPRUS AGGREGATES TO ALKALI AGGREGATE REACTION

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF APPLIED
SCIENCES
OF
NEAR EAST UNIVERSITY

by

ANDISHEH ZAHEDI REZAIEH

IN PARTIAL FULFILLMENT OF
REQUIREMENTS
FOR THE DEGREE OF MASTER OF SCIENCE
IN
CIVIL ENGINEERING

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last name: ANDISHEH ZAHEDI REZAIEH
Signature:
Date:

ÖZET

Alkali-Agrega Reaksiyonu (AAR), tüm dünya genelinde betonarme binalarda yüksek masraflı rehabilitasyon gerektirecek ciddi zararlara neden olan önemli bir durabilite (dayanıklılık) problemi olarak kabul edilmektedir.

Ancak, bu ciddi beton durabilite problemi yüzünden harcanacak masrafların, beton üretiminde kullanılcak malzemelerin (agrega, çimento ve ek katkı materyallerinin) yerel çevresel koşullar altındaki performasının önceden tespit edilmesi ile en aza indirgenmesi mümkündür.

Bu çalışma esnasında AAR hakkında detaylı bir literatür taraması gerçekleştirilmiştir. Güney Kıbrıs'a ait Trodoos Dağı'ndan elde edilmiş agregaların performansı ile ilgili kısıtlı bilgiye ulaşılsa da, Kuzey Kıbrıs'a ait Beşparmak Dağları'ndan elde edilmiş agregaların performansına dair herhangi bir bilimsel veriye ulaşılamamıştır.

Bu eksiklik göz önünde bulundurularak, detaylı ve sistematik deneysel çalışmalar yürütülmüş ve bu şekilde Kuzey Kıbrıs agregalarının hem Alkali-Silika hem de Alkali-Karbonat reaksiyonları karşısındaki performansı araştırılmıştır.

Güney Kıbıs'tan (Trodos Dağı'ndan) elde edilen agregalar da çalışmalara dahil edilerek bu bölgeye ait agregalara dair daha güncel veriler de elde edilmesi amaçlanmıştır.

Deneylerde esas olarak Kıbrıs koşullarına uygun, düşük hidratasyon ısılı ve en yaygın çimento olan CEM II kullanılmıştır. CEM II'deki ek katkı materyallerinin AAR dayanımındaki etkisinin de daha iyi anlaşılması için CEM I (Normal (Katkısız) Portland Çimento) da kullanılmıştır.

Detaylı çalışmalarla elde edilen sonuçlara göre, Kuzey Kıbrıs agregalarının CEM II ile kullanımlarının hem Alkali-Silika hem de Alkali-Karbonat reaksiyonlarına neden olma potansiyeli olduğu tespit edilmiştir. Güney'den alınan agregaların ise ciddi şekilde reaktif olabileceği teyit edilmiştir.

Deneyler sonucunda elde edilern veriler, Beşparmak Dağlarından alınan agregalar ile CEM II karışımı ile yapılan numunelerde %0.1'den fazla boy uzaması kaydedildiğini göstermektedir. Bu nedenle bu agregalar takip edilen standarda göre iki tip reaksiyon için de "reaktif olması muhtemel" olarak sınıflandırılmıştır. Güney Kıbrıs Trodos Dağ'ından alınan agregalar ile CEM II karışımı ile yapılan numunelerde ise % 0.279'dan fazla boy uzaması kaydedilmiştir. Bu nedenle bu agregalar takip edilen standarda göre iki tip reaksiyon için de “zaralı (reaktif)” olarak sınıflandırılmıştır.

Anahtar kelimeler: Alkali-Agrega Reaksiyonu, Alkali-Silika Reaksiyonu, Alkali-Karbonat Reaksiyonu, Kuzey Kıbrıs Agregaları, Güney Kıbrıs Agregaları.

I dedicate this thesis to my dad (Mehdi), my mum (Sima) for their moral, financial and spiritual support from my childhood up to this great achievement. I hope that this achievement will complete the dream that you had for me all those many years ago when you chose to give me the best education you could.

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ABSTRACT

Alkali- aggregate reaction (AAR) is accepted as one of the most deleterious concrete durability problems, causing severe damage in reinforced concrete structures all around the world. Rehabilitation of those damaged structures usually require significant amount of budget and expertise.

However, it is possible to minimize the damage and all related expenses, if the compatibility and the performance of materials (e.g. aggregate and all cementing materials) used in concrete manufacture are verified considering the local environmental conditions.

In this study, a detailed literature survey was carried out with special focus on the susceptibility of Cyprus aggregate to AAR related problems. Even though some limited information is founded on South Cyprus (Trodos Mountain) aggregates performance, no scientific data was founded on the AAR performance of North Cyprus (for Beşparmak Mountains). Therefore, a systematic experimental campaign was designed and carried out, in order to investigate the performance of North Cyprus aggregates against both categories of AAR, which are Alkali-Silica Reaction (ASR) and Alkali-Carbonate Reaction (ACR). Investigations were also extended to cover the testing of aggregates obtained from South Cyprus in order to provide further and more recent data on the aggregate originating from Trodos Mountain as well.

CEM II was chosen as the principal cement to be used in the experiment, since it is the most widely used cement in Cyprus due to it relatively lower rate of heat of hydration that is suitable for the local conditions. Additional samples made with CEM I (OPC) were also tested in order to check the effect of supplementary cementing materials (SCMs) that are present in CEM II, on the AAR performance of mortar samples.

Results indicate that aggregates obtained from Beşparmak Mountains used in combination with CEM II has more than 0.1% length change so according to the standard, can be potentially reactive for both ACR and ASR. The reactivity of the aggregate obtained from South Cyprus (Trodos Mountains) was once again confirmed, it has 0.279% length change so according to the standard South Cyprus aggregate in combination with CEM II is deleterious.

Keywords: Alkali- aggregate reactions, Alkali silica reaction, Alkali carbonate reaction, North Cyprus aggregates, and South Cyprus aggregates

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 General Concepts

Concrete is one of the most advantageous and most economical materials used worldwide in construction industries; however the performance of this highly preferred material is limited due to some durability problems that it may face throughout its service life. AAR is one of these durability problems which have potential to cause severe deterioration in concrete. Alkali aggregate reaction (AAR) has two categories: Alkali Carbonate Reaction (ACR) and Alkali Silica Reaction (ASR). ACR is commonly accepted to occur less frequently compared to ASR; therefore, this type of AAR is not frequently considered as the main focus of the related studies. On the other hand, ASR, being relatively much more common, is specially studied in detail. ASR produces a special gel which absorbs the water and expands in moist areas. AAR, especially the ASR, has several deteriorating effects on structures; like discoloration, expansion and deformation, severe cracklings, pop-out, and changes on mechanical properties of concrete.

Some elements are absolutely essential for initiating the AAR, like:

- Existence of sufficient amount of alkali,
- Existence of moisture and;
- Existence of reactive aggregates. (Berube & Fournier, 2000)

Elimination of one of these elements will stop the AAR. (Berube & Fournier, 2000)

Applying some prevention methods prior to the manufacture producing of concrete such as using non-reactive material, reducing the amount of alkali in concrete, using SCM, using lithium base compounds and precaution against external moisture can contribute to minimize the occurrence of AAR. If some signs of AAR appear after the casting of concrete, using remedial actions such as limiting moisture ingress, chemical treatment, using reinforcement, and slot cutting and as last choice, replacement are necessary. (U.S. Department of transportation, 2013), (Munn et. al., 2011)

1.2 Significance of Study and the Definition of the Problem

There is a wide range of aggregates around the world which are classified as reactive. Some of the aggregate types which also present in Cyprus may initiate AAR such as quartzite, sandstone, shale and siliceous limestone detailed literature review was carried out. As a result of this literature survey, it was observed that there is no study investigating the susceptibility of North Cyprus aggregate to AAR. So in this set of material, the problem in Cyprus is; there is no experimental data which shows the reactivity level of aggregates in Cyprus.

1.3 The objective of study

The objective of this study is to provide information on the level of reactivity of Cyprus aggregates in a systematical data-based manner with the aid of standard test methods recognized internationally, such as AAR-2 (ASTM C 1260 (ultra-accelerated mortar-bar testing)) and AAR-5(Rapid preliminary screening test for carbonate aggregates). Therefore,

1. A significant contribution to the related literature will be made by providing detailed and systematical experimental data on the performance of various Cyprus aggregates used in combination with typical cements used in Cyprus.
   In this way:
2. More insight on AAR Occurrence in existing buildings will be gained.
3. The provided information will also serve to suggest adequate precautions that can be taken before the manufacture of concrete.

1.4 Outline of the study

This thesis contains four chapters; chapter one briefly describes the thesis’s subject and aims. In literature review as chapter two, the theory of concrete durability with a special emphasis on AAR problem and its mechanism, as well as, influencing factors, test methods, prevention methods and information on Cyprus geology and available materials (both aggregates and typical cements) are discussed in detail. In methodology as chapter three, selection of the critical materials used in Cyprus, selection of adequate test methods and the design of experimental comparing are explained in detail. Results and discussions as chapter four, the results obtained and the discussions are presented and chapter five is dedicated to the conclusions.

CHAPTER 2

THEORETICAL BACKGROUND

2.1 Concrete

Concrete is one of the most construction material composed of water, coarse and fine aggregate and cement (binder) which fills the space between aggregate and stick them together. Concrete production is time-sensitive. Concrete become stronger and capable of bearing loads with the initiation of hardening process. There are two types of concrete, ready mix plants and central mix plants. A ready mix plant is the mix of all ingredients except water, while a central mix plant is the mix of all ingredients with water; this method needs more quality control than ready mix (Neville, 1996).

After mixing all ingredient and place it, curing the concrete is absolutely essential to achieve best strength and hardness. For achieving the strength, cement needs a moist and controlled environment.

Good concrete elements are the elements which has a good durability. Durability is defined as the ability of concrete to resist chemical attack, abrasion and during its life time. If the concrete elements have factors below, they will remain durable;

- The cement paste has low permeability
- It’s better to made with well graded aggregate.
- The ingredient should have minimum impurities such as Sulphates, Chlorides, alkali and etc.

So in the absence of one or more of these factors, the concrete will face with the durability problem. Two major types of durability problem are: (ACI 201.2R-08, 2008)

- Durability against physical action
- Durability against Chemical action

Physical durability consists of:

- Temperature stresses
- Freezing and thawing action

And chemical durability consists of: (Neville, 1996)

- Sulfate attack
- Chloride ingress
- Corrosion
- Alkali Aggregate Reaction

2.2 Alkali Aggregate Reaction

2.2.1 Background

Thomas Santon (Munn et. al., 2011) at California Department of Transportation detected cracking in concrete which was occurred due to certain aggregate reacting with cement alkalis for the first time; therefore he called this phenomena Alkali-aggregate reaction (AAR). Since then, several scientists continue researching on AAR, with the main areas of focus as: (Fournier & Berube, 2000)

1) Better understanding of mechanism of AAR in concrete.
2) Identification of reactive aggregate and developing test methods to assess the reactivity of aggregates.
3) Developing new method to prevent initiation of AAR in new structures
4) Developing remedies for rehabilitation of existing structures affected by AAR.

2.2.2 Alkali Aggregate Reaction (AAR)

When a highly basic fluid which consist of alkali hydroxides ions like (K^+, Na^+ — OH^-) fill the pores in concrete and the aggregate in concrete are chemically unstable in the high pH environment, the concrete encounter with distresses such as cracking, losing serviceability, and etc. (Fournier & Berube, 2000). This internal chemical reaction is recognized as alkali aggregate-reaction (AAR). The source of alkalinity in these phenomena is from cement and aggregate but some external sodium or potassium can contribute the reaction (Munn et. al., 2011). The reaction cause the formation of a gel which absorbs water and then expands, due to this internal pressure, the micro cracks gradually appear. (ACI 221.1R-98, 1998)

Two types of AAR are generally recognized: 1) Alkali- carbonate reaction (ACR) and 2) Alkali Silica reaction (ASR)

2.2.2.1 Alkali-Carbonate Reaction (ACR)

Argillaceous dolomitic limestones are susceptible to this reaction. Two mechanisms contribute to the carbonate reaction: 1) Crystallization of brucite and calcite during the dedolomitision and 2) Sorption of alkalis by clay.

The dedolomitision causes expansion

$$CaMg(CO_3)_2 + 2\,(Na,K)OH \rightarrow Mg(OH)_2 + CaCO_3 + (Na,K)_2CO_3$$

Dolomite Alakli Hydroxide Brucite Calcite Alkali Carbonate

This reaction is known to not to occur frequently to this phenomenon are less common and suitable for using in concrete industry (Fournier & Berube, 2000). The aggregate sensitive to ACR have characteristics texture which can identify by some tests such as ASTM C 441 or ASTM C586-11.

The dedolomitisation involves the reaction of alkali carbonates with portlandite in concrete and yield to reform alkali hydroxides (Fournier & Berube, 2000).

$$(Na,K)_2CO_3 + Ca(OH)_2 \rightarrow CaCO_3 + 2\,(Na,K)OH$$

Alkali carbonate Portlandite Calcite Alkali Hydroxide

No gel is produced as a result of this reaction.

Recently the theory which was introducing by Katyama (Katyama, 2010) in the early of 20th century suggests that ACR is the combined reaction of dedolomitisation of dolomitic aggregate and expansive ASR of cryptocrystalline was confirmed by using tests like SEM observation, polished section and etc. (Katayama, 2010)

2.2.2.2 Alkali-Silica Reaction (ASR)

Alkali-silica reaction is relatively more common and it has negative effect on the mechanical properties of concrete (Marzouk & Langdon, 2000) this reaction is between alkaline pore solution and silica mineral like cryptocrystalline quartz and opal. Higher solubility of silica mineral in high pH solutions means higher likelihood of reaction occurrence. The reaction yields the formation a gel that absorbs water and expands in moist areas (Munn et. al., 2011). The expansive pressure by the silica gel causes crackings and deteriorations in concrete. The quantity of gel depends on the amount of silica; if the amount of silica increases, the expansion will be increased.

The composition of this gel has been studied by several of researchers (Lindgard et al., 2012); they stated that, this gel has high contents of silica and low contents of calcium and alkalis. The formation of silica gel depends on composition and the texture of the aggregate but the composition of silica gel doesn’t depend on the nature of aggregate.

Two categories of ASR are recognized:

1) Quartz- bearing rock which reacts slowly in the early ages and then the expansion and cracks start to appear from 10 to even 25 years of concrete, when concrete is exposed to conditions favoring the reactions
2) The rocks incorporate with Silica. This type of rocks contributes to extensive expansion and cracking on the early age of concrete when concrete is exposed to conditions favoring the reactions

ASR damages both macroscopic and microscopic properties of material, for instance; for macroscopic damages, the changes in length can be mentioned, as Hayman et.al.(Hayman et al., 2010) stated that deleterious of concrete is when the expansion greater than 0.040%. For microscopic damages, significant difference between modules of elasticity of the gel and cement paste or aggregate can be mentioned (Chen et al., 2010).

2.2.3 Mechanism of Expansion

Pore solution of concrete is formed of potassium (K^+) and sodium (Na^+) ions and hydroxyl ions (OH^-). In highly basic environment, the hydroxyl ions (OH^-) attack the Silanol (Si-OH) and

Siloxane (Si-O-Si) groups of reactive silica and yield the reaction given in the following equation. (Fournier & Berube, 2000)

$\text{Si-OH} + \text{OH}^- + \text{Na}^+ \rightarrow \text{Si- O- Na} + H_2O$

$\text{Si-O-Si}+2\ \text{OH}^- + 2\text{Na}^+ \rightarrow 2(\text{Si- O- Na}) + H_2O$ (U.S. Department of Transportation, 2013)

Under this attack, microcrystalline quartz with other aggregate particle form a viscous and hygroscopic (Gillott, 1995) gel called "alkali- silica gel" (Fournier & Berube, 2000) Absorption of water due to the difference in free energy of water and various species and the gel, tensile stresses built up and then cracking appear.

Several studies (Thomas, 1998, Fournier & Berube, 2000, Thomas, 2001) has stated that, for having the significant expansion, the existence of calcium hydroxide [$Ca(OH)_2$] is essential. Although the exact roles of calcium in gel expansion remains equivocal, a series of mechanisms have still been proposed:

1) The existence of calcium cause ion-exchanging process with OH^- of the cement paste and causes spreading of gel freely and gradually the expansive properties loses. (Fournier & Berube, 2000)
2) Calcium replaces alkalies and causes regenerating of that for other reaction. (Thomas, 2001)
3) In the absence of calcium, the silica gel will be formed without causing damage. (Thomas, 1998)

As mentioned before the precise role of calcium is still vague, but it is clear that calcium must be available for having significant expansion, thus reducing the calcium (i.e. using pozzolan) causes the reduction of alkali-silica expansion.

2.3 Factors Contributing AAR (Favoring Conditions)

There are three requirement factors need to alkali aggregate damaging initiate: (Fournier & Berube, 2000)

1) Sufficient amount of alkali must be present
2) Sufficient moisture must be present in the pore structure of concrete
3) Sufficient quantity of reactive aggregate must be present

2.3.1 Sufficient Amount of Alkali

Portland cement is the primary source of alkali in cement and other material contribute additional alkalis for reaction. The source of alkali can be any of the following list:

- Portland cement
- Aggregates
- Chemical admixture
- External sources(e.g. deicing salt and sea water)

The amount of alkalis expressed in terms of Na_2O_{eq} (equivalent sodium) which is calculated from

$Na_2O_{eq} = Na_2O + 0.658 \times K_2O$

Na_2O and K_2O must be the mass percentages of sodium and potassium oxide in Portland cement. The percentage of alkalis in Portland cement is in the range of 0.2 to 1.3% for most European countries. Based on Santon's works (Chen, 2010) the expansion from the alkali-silica reaction does not occur if the alkali content of cement is below 0.6% $Na_2O_{eq.}$ Migration of alkalis during moisture movement, electrical current, surface evaporation, cathodic protection and penetration of alkalis from external sources, may increase the amount of sodium and potassium ions, thus contribute to increase alkali content of concrete and increase deteriorate expansion(Fournier & Berube, 2000)(U.S. Department of Transportation, 2013).

It should be considered that the expansion occurred in field may be more than the expansion in laboratory expansions done with the same material and same amount of alkalis, since the amount of alkalis may be lost due to leaching involved in the test (Thomas et al., 2006).

2.3.2 Sufficient Moisture

Alkali aggregate reaction normally cease when the internal relative humidity is lower than 80 to 85 % (Fournier & Berube, 2000). As mentioned before, alkali silica gel absorbs water for swelling and expanding on concrete.

Several studies have been carried out on the effect of water on ASR expansions. Multon and his colleagues (Multon.& Toutlemonde, 2010) carried out an experiment about the effect of water and moisture on the ASR expansion; they stated that late water supply causes new ASR expansion and whenever the water supplied at an ASR damaged structure, the ASR gel already produced, can rapidly swell.

Massive concrete elements are more at the risk of AAR due to the high internal humidity which remains in that element. Berube (Berube etal., 1998) stated that using Silanes and Siloxanes for face treatment of thin concrete will limit the amount of moisture ingress and in this way contribute to reduction of AAR expansion.

As US Department of Transportation (U.S. Department of Transportation, 2013) expressed that, "Local difference in moisture availability with in the same structure can result in very different level of ASR damage occurring within the same structure".

2.3.3 Sufficient Quantity of Reactive Aggregate

Silica is the main cause of alkali-silica reaction, however all forms of silica do not react deleteriously with pore solution of concrete. For instance, opal is highly reactive and Greywacke and quartz sand are stable, although opal, greywacke and quartz sand are silica mineral with same chemical composition but. So there are some silica minerals which considered being alkali-silica reactive like: opal, volcanic glass, chert, microcrystalline and strained quartz (U.S. Department of Transportation, 2013). The reactivity level of alkali-silica of aggregate increases with:

1) The increase in the amount of microcrystalline quartz
2) The decrease in the size of aggregate
3) The increase in the quantities of reactive particles in aggregate.

Reactive material can be detected by an experimental petrography.

Potentially alkali-reactive rocks and mineral phases are mentioned on the table below (Fournier & Berube, 2000).

Table 2.1: Potentially alkali- reactive rocks and mineral phases (Fournier & Berube, 2000)

Alkali- silica reactive material and rocks	
Alkali-reactive quartz- bearing rocks	
Rocks	Chert, Flint, quartzite, quartzarentine, sandston, siliceous limston, colconic rocks, sedimentary such as Siliceous limestone or sandston, Gabbro and Diabase (with Sio_2 > 50% wt)
Reactants	Chalcedony, microcrystalline quartz, macrocrystalline quartz
Alkali-reactive-silica mineral	
Rocks	Opal Sedimentary rocks Such as sandstone or shale , volcanic rocks: acidic, intermediate and basic (e.g. Tuff, perlite, obsidiam)
Reactants	Opal, tridymite, cristobalite,acidic,intermediate, and basic volcanic glass, Artificial glass, beekite
Alkali Carbonate reactive material and rocks	
Rocks	Dolomitic limestone, calcitic dolostone, calcitic dolostone
Reactants	Dolomite, active clay minerals after dedolomitization

Elimination of one of these three elements will cease the alkali-silica reaction.

2.4 Other Factors Influencing Alkali- Aggregate Reactivity

2.4.1 Environmental Effects on AAR

The Alkali aggregate reaction affected elements of concrete which exposed to cyclic exposure to wind, rain and sun or the concrete elements in marine regions have more expansion. Berube E\et. al.(Berube et al., 1996) worked on concrete cylinders which exposed in different environments and then stated that

1. The specimens in wetting and drying cycles has less expansion but they have several cracks
2. The specimens in freezing thawing cycles have significant expansion and they have several micro cracks.

2.4.2 Water to Cement Ratio and Concrete Permeability

Reduction in water to cement ratio in concrete affect the mechanical properties of concrete like lower concrete permeability also reduce the movement of moisture in concrete. As mentioned before, the existence of moisture is one of the critical elements lead to development of deleterious expansion of AAR. As Berube and Fournier (Fournier & Berube, 2000) declared, reduction in w/c ratio will reduce the AAR expansion.

2.4.3 Temperature and Heat of Hydration

In the moist condition, AAR expansion will be faster at high temperature but it will cease in short time, in contrast at lower temperature the expansion is slower (Berube & Fournier, 2000) but it will proceed for long time. Massive concrete structures are more at risk of AAR due to the time for releasing the hydration heat of cement.

2.4.4 Air entrainment

Using the air entrainment in concrete reduces the AAR expansion but using this material is not enough for preventing AAR cracklings and expansions completely. (U.S. Department of transportation, 2013)

2.4.5 Reinforcement

Using reinforcement (straps, steel plates, or beams) reduces the expansion of AAR, but even using the restrain cannot provide control the cracking of AAR and cracking is inevitable.

2.4.6 Particle Size and Angularity

Numerous studies have been carried out about the effect of the particle size and particle angularity.

Earlier research of Vivian (Vivian, 1950) showed that for opalline aggregate, maximum expansion of ASR is when the particle is in the range of 0.07mm to 0.85mm and for the silica particle, larger or smaller, it reduce the expansion. Then Hobs et. al.(Hobbs & Gutteridge, 1979) and Han et.al. (Han & fang, 1984) Worked on the opalline silica and showed that the expansion of mortar bar increased when the reactive particle is in the range of 0.02 mm to 0.05 mm but below 0.02 mm there is no sign of expansion was observed. Zhang et. al. (Zhang etal., 1999) stated that for silicious aggregates the maximum expansion occurred when the particles are in the range of 0.15 to 10 mm. Multon et. al (Multon et al., 2010) worked on the reactive siliceous limestone and stated that the particles lower than 16 µm do not cause expansion while the particle in the range of 0.63-1.25 mm cause the large expansion. Cyr et. al.(Cyr et al., 2009) worked on the finely ground reactive aggregates of various types, and stated that they reduce the expansion . Zhang et. al. (Zhang et al., 2009) worked on the influence of the large aggregates which were reactive, they state that large aggregates reduce the expansion at early age and increase it later. Multon et al (Multon et al., 2008) stated that generally the particles larger than 1 mm are more endanger than the other. They showed that the expansion for coarse aggregate is seven times more than small particles. Ramyar et. al.(Ramyar et al., 2005) worked on the effect of both size and angularity of particle and state that the angularity has neglect able effect when the aggregates are too small or too large but for intermediate size, the angularity influence is more evident.

In spite of all these studies, it is complex to generalize the influence of particle size and angularity of reactive aggregates, so more comprehensive research should be performed to extend the limit of the present investigation.

2.4.7 Use of Fiber

Using fibers in addition to steel bar could accelerate the time of the construction and make it more economical and moreover this, it can reduce the expansion and cracking due to ASR.

In concrete, Turanli et. al.(Turanli et al., 2001) used steel microfiber in fiber volume content range from 1% to 7% then they stated that using the steel fiber reduce the expansion and cracking due to ASR significantly. Park at. al.(Park et al., 2004) carried out an experiment of study on mortar containing aggregates of waste glass and steel fiber, then they stated that adding of 1.5 % of fiber to concrete can reduce the expansion up to 40%. De Carvalho et al. (De carvalho et al., 2010) Carried out the test on the mortar contain Fiber (1% and 2%) and stated that existence of fiber in the mortar bar can reduce significantly (60%) the expansion by AAR.

Although several studies are carried out on the effects of fiber, phenomenon is not still well understood well. More research should be performed to extent the limit of the present investigation.

2.4.8 Sodium Chloride

Sodium chloride in most of the countries used as deicing salts. Penetration of sodium chloride contributes to AAR to increase the AAR related expansion. If the permeability of concrete is high, deicing salts will be absorbed and then more expansion occurs.

2.4.9 Sulphate Exposure

Sulphate can contribute the AAR to increase the expansion. If the concrete encounter with the ground water, which is fully, reaches of sulphate, more expansion will occur.

2.5 Symptoms of ASR

As mentioned before, under the certain conditions, the ASR can initiate in concrete and cause damages. ASR has some symptoms. Common symptoms of ASR are: (U.S. Department of transportation, 2013)

- Discoloration
- Expansion and deformation
- Cracking
- Crushing of concrete
- Pop- out
- Effect on mechanical properties of concrete

2.5.1 Discoloration

The AAR cracks bordered by brown or white color which affect the appearance of the concrete elements. Normally discoloration occurs in concrete elements which are exposed to water or rain.

Figure 2.1: Discoloration cause by AAR (U.S Department of Transportation, 2013)

2.5.2 Expansion and deformation

In presence of water, the ASR gel is capable of swelling and then causing the expansion in concrete members. ASR expansion influence the performance of entire structure by increasing punching shear, tensile strain and etc. (Lingard et al., 2012) (Fournier & Berube, 2000). Due to the expansion, the elements will face with deformation. Using steel restrains can contribute to reduce the expansion and deformations, but it wouldn’t cease all expansion of the concrete elements.

2.5.3 Cracking

Normally, one of the most common symptoms of ASR is map cracking (Fournier & Berube, 2000) which form randomly- oriented cracks on the unrestrained concrete elements especially on the surface of concrete. These cracks can move in all directions.

The patterns of cracks vary due to geometry or shape of concrete element, the reinforcement and applied load to the concrete member. (Burrows, 1998)

Although using reinforcement and restrains in concrete can reduce the ASR expansion but these restrains cannot significantly reduce the surface cracking. If the restrain reduce the expansion in one direction, more expansion and then more cracks appear in other direction. (Lingard et al., 2012) (U.S. Department of transportation, 2013)

Cracking increase where the renewable supply of moisture present such as in the case of the elements exposed to the rain in columns or bridge foundation's elements (Thomas et al., 2011). Cracking become more severe when the element is expose to different climate cycle, like, sunny, rainy and windy weather. (Lingard et al., 2012)

Apart from map cracking, The ASR affected elements confront with macro cracking. Although macro cracking occur less than map cracking, macro cracking can enter more than 25 to 50 mm (In rare cases, it can increase till 100 mm) of surface and the width of them can vary from 0.1 to 10 mm on the surface of concrete. (Fournier & Berube, 2000)

Present of cracks can affect the serviceability of concrete element. Cracks increase the corrosion of reinforcement by providing a route for air, water and chlorides to reach the steel in concrete.

Figure 2.2: Cracking by AAR (U.S Department of Transportation, 2013)

2.5.4 Pop-out

Pop-outs occur when the frost action causes the expansion of unsound aggregate, also alkali-silica reactive aggregate can cause pop-out in concrete. Pop out usualy happen after the expansion and deformation.

Figure 2.3: Pop out (U.S Department of Transportation, 2013)

2.5.5 Effect on Mechanical Properties

2.5.5.1 Effect of Alkali on Drying Shrinkage

Burrows (Burrows, 1998) carried out an experiment on 104 concrete panels which was made with27 different cements and after fifty three years he stated that high alkali cement has more shrinkage than low alkali cement. Blain et al (Blaine et al., 1971) carried out a test on mortar bars with 199 different cements and then he stated that high alkali mortars have more shrinkage.

So, higher cement alkali content is more sensitive to shrinkage under drying condition for cement past and mortar, but the validity of their finding is not clear for the concrete.

2.5.5.2 Effects of Alkalis on Ultimate Strength and Development of Strength

Blaine et al. (Blaine et al., 1971) carried out an experiment on 199 different Portland cement and then they stated that the cement with high alkali content has low ultimate strength. Osbaeck (Osbaeck, 1984) performed a test on different kind of cement and then he stated that higher alkali content in cement cause decreasing the ultimate strength and increasing the strength development in early age. Gouda (Gouda, 1986) carried out a test on concrete with low alkali content (0.6% Na_2O_e) and high alkali content (1.78% Na_2O_e) and then he stated that cement with low alkali content has very low strength development at early ages. Alexander et. al. (Alexander et al., 1990) stated that the cement pastes with high alkali have very low compressive strength.

Most studies has been performed on the effect of alkalis on the mechanical properties on cement past and mortar specimens, more over more studies should performed on the effect of alkalis on the mechanical properties on concrete.

2.5.5.3 Effect of Additional Alkali on Properties of Concrete

Smaoui et. al. (Smaoui et al., 2005) carried out an experiment by adding NaOH on the concrete, which is usually done for evaluating the alkali-silica reactivity potential of aggregate and the effect of ASR on the mechanical properties of concrete. They stated that adding alkali to the concrete has more effect on the compressive strength rather than the modulus of elasticity for compression. Adding alkalis can reduce the early and ultimate strength but its effect on the modulus of elasticity is not significant.

The present of one or many of these symptoms can't indicate that ASR is the only factor for damage observed.

2.6 Test Methods

Aggregate is one of the most important material used in concrete manufacture, using test method to classify and describe the aggregate is needed. Test method should be rapid, reliable and simple (Fournier & Berube, 2000). The test methods for evaluating the reactivity of material subcategorized in two sections:

1) ASR evaluating aggregate reactivity
2) ACR evaluating aggregate reactivity

2.6.1 ASR Test Methods for Evaluating Aggregate Reactivity

Since 1930, when Santon discovered ASR, different tests methods have been proposed for evaluating the reactivity of aggregates. In the following sections, the methods which are in common will be explained. In this research, mainly ASTM and RILEM methods are studied.

2.6.1.1Petrographic Methods

Petrographic methods used as a “ first step” for determining the reactivity of material, so the purpose of this test method is to get the characteristics of material such as finding mechanical, physical and chemical properties of rock. (Jensen & Sibbick, 2006) This test method can be both quantitative and qualitative; the quantitative describe all or some components but it would not be able to state their proportion, in contrast, the qualitative express the proportion of aggregate.

This test usually uses three quantitative methods to gaining information about rock composition:

1) Grain counting, this method is used for coarse aggregate when the aggregate particle can divided into different rock group by hand sorting. The result will show as weight percent of total weight. (Jensen & Sibbick, 2006) (Haugen et al.)(Lindgard et al, 2010 b)
2) Point counting, this method is used when the aggregate particle cannot separate easily. This method is most cases is the most accurate method. In this method thin section is investigated by petrographic microscope and point counter device form orthogonal grid and then result come out in volume percentage. (Jensen & Sibbick, 2006) (Haugen et al.)(Lingard et al, 2010 b)
3) Whole rock petrographic, “if the aggregate which is used uniform characteristics then the thin section of total aggregate particle can be produced to determine of its potential alkali- reactivity”. (Jensen & Sibbick, 2006) (Haugen et al.)(Lindgard et al, 2010 b)(U.S Department of Transportation , 2013)

The selection of technique for establishing the reactivity of an aggregate is based on an initial macro- examination of aggregates of sample.

Point counting has two different procedures, in some countries the reactivity of entire aggregate particle determines and in contrast in some other countries the reactivity of each point determine. After the petrographic, the petrographer places each rock type in one of the three “reactivity class”: (Jensen & Sibbick, 2006)

I. Unlikely to be reactive
II. Alkali-reactive unsure
III. Very likely to be reactive

ASTM C 295 (Petrographic Examination of Aggregates for Concrete) and AAR-1 (Petrographical examination) are the most used petrographic method in the world. ASTM C 295 used for gravel and sand, crushed stone and drilled core. AAR-1 as a new test method used for finding the quantity and identify of rock type which may react with alkalis. It used for gravel, sand and crushed rocks. The RILEM survey (Jensen & Sibbick, 2006) indicated that, using petrographic analyses is in common when encountered with alkali-reactive aggregate in most countries.

The main difference between ASTM C 295 (Petrographic Examination of Aggregates for Concrete) and AAR-1 (Petrographical examination) is the use of different methods to obtain information; ASTM C 295 uses grain counting as preferred method but AAR-1(Petrographical examination) both point counting and grained counting are used as preferred method. (Jensen & Sibbick, 2006)(Owsiak, 2007)

If petrographic find the aggregate is potentially reactive, furthers examination are recommended to use or proper precaution must be considered (Munn et. al., 2011).

2.6.1.2 Chemical Test

Mielenz and Benton in late 1950's founded an initial test method for determining the reactivity of aggregates. (Jensen & Sibbick, 2006)

ASTM C 289 (Chemical Test) uses this method to find the reactivity of aggregate and then categorize the aggregate in three categories "innocuous", "deleterious" and "potentially deleterious". In this test method, crushed aggregate should be immersed in 1N NaOH solution for 24 hours and then solution should be analyzed for dissolved silica and alkalinity. This method should be performed by an experienced laboratory's staff (Munn et. al., 2011). Chemical test is rapid but its result is not decisive (Owsiak, 2007).

2.6.1.3 Accelerated Mortar Bar Test (AMBT)

This test method was introduced by Oberholster and Davides in late 1970's in South Africa (Munn et. al., 2011). ASTM C 1260 (Accelerated mortar bar test (AMBT)) and AAR-2 (ultra-accelerated mortar-bar testing) are the most used accelerated mortar bar test (Chen et al., 2010). The casting mortar bars which was made by an aggregate complying with ASTM C 1260

(Accelerated mortar bar test (AMBT)) and AAR-2 (ultra-accelerated mortar-bar testing) grading, placed in water at room temperature for 24 hours, and then for next 24 hours, the mortar bar stored in 80℃ in an oven. Later the mortar bars are removed from oven and the length changes is measured, after that for 14 days submerse the bars in 1 N NaOH solution for 80℃. During these 14 days, the length of the mortar should be measured periodically and finally after 14 days, the total expansion will be measured.

Although the expansion limits have not yet been finally approved internationally, ASTM C 1260 (Accelerated mortar bar test (AMBT)) and AAR-2 (ultra-accelerated mortar-bar testing) suggest that if the expansion is less than 0.10%, it's considered as none-expansive. If the expansion exceeds 0.20%, it's considered as expansive material and if the expansion is between 0.10% to 0.20%, it's considered as potentially reactive material. Shayan and Morris (Shayan & Morris, 2001) worked on the mortar bar test method and declared that if the expansion in first 21 days is 0.1% or in first 14 days is 0.08%, the aggregates are known as slow reactive aggregate.

2.6.1.4 ASTM C 227

This test method is similar ASTM 1260 (Accelerated mortar bar test (AMBT)) and AAR-2 (ultra-accelerated mortar-bar testing) since it uses the mortar bars as testing samples, however storage conditions and duration are different. In this method when the mortar bar is made by aggregate complying with standard grading (aggregate to cement ratio should be 2.25 and the cement contains 0.8 % Na_2O_e (Owsiak, 2007)). They store at 38℃ water for six months and measure the length of the bar continuously for two years. ASTM C 227 (Mortar Bar Method) is convenient for determining the reactivity of aggregate but it needs experienced laboratory's staff. (Munn et. al., 2011)

2.6.1.5 Test Methods on Concrete Samples

Like mortar bar test, concrete prism can be controlled by some test methods. ASTM C 1293 (Length Change of Concrete Due to Alkali Silica Reaction), AAR-3 (concrete prism testing), AAR-4 (ultra-accelerated concrete testing) are the most used concrete test methods. (Fournier & Berube, 2000)(U.S. Department of Transportation, 2013)(Lindgard et al., 2010)(Sims & Nixon, 2003)

2.6.1.6 ASTM C 1293 (Length Change of Concrete Due to Alkali Silica Reaction)

Concrete prism test (ASTM C 1293), considered the most general, accurate and effective test for finding reactivity of aggregate because it is more realistic compare to Accelerated mortar bar test (AMBT). In this test method the alkali content of used cement reach 1.25% by mass of cement (U.S. Department of transportation, 2013).When the concrete cube is prepared, it store in 38℃ water for one year. During this period, the expansion should measure regularly. The expansion limit for this test method declares that if the expansion is more than 0.04% for one year, the aggregate will be reactive.

Some problems have been reported about this test method. Thomas et. al. (Thomas et al., 2007) stated that during the test period, more than 35% internal alkalis leach out and during the first three month, leach out is more than 20 %. Using this test method needs long period of time so few agencies use this test method to specify the reactivity of material, due to that, researcher try to accelerate this method by increasing the storage temperature to 60℃ and decrease the duration of test to few month, Ideker et. al. worked on accelerate version of concrete prism test and stated that the expansion due to accelerate method is less than standard concrete prism test. (U.S. Department of transportation, 2013)

2.6.1.7 AAR-3 (Concrete Prism Testing)

Accelerated concrete prism test method is called RILEM AAR-3. This test method consists of the same procedure as ASTM C 1293 includes. The difference is the expansion limits; in this test method if the expansion after 12 month is less than 0.05% so the aggregate is non- expansive, if the expansion exceed 0.10%, the aggregate consider expansive. There is no agreement for the range 0.05% to 0.1%, this aggregate in the absence of experience staff is considered as potentially alkali-reactive.

2.6.1.8 AAR-4 (Ultra-Accelerated Concrete Testing)

This test method is similar to AAR-3 but its storage condition is different. At this test method, the cube cements store at 60℃ instead of 38℃ (Lingard et al, 2010). The expansion limit of this test declares that if the expansion is less than 0.02% after 3 month, it is considered as non-expansive aggregate. According to the defined ranges, after 15 weeks if the expansion is less than 0.03% it’s non-reactive, if it’s more tha0.03% it is considered as potentially reactive and it needs to have special precautions to minimize the risk of ASR.

Table 2.2: Test methods for ASR

Test method	Test type	Test duration
ASTM C 289	Aggregate react with alkaline solution at 80℃	24 hours
ASTM C 295 AAR-1	Using petrographic method	-
ASTM C 227	Mortar bar stored in high humidity containers at 38 ℃	First measure 14 days, then subsequence measure at 1,2,3,4,6,9 and 12 months
ASTM C 1260 AAR-2	Mortar bars are immersed in 1M NaOH solution at 80 ℃	14 days
ASTM C 1293 AAR-3 AAR-4	Concrete bars are soaked in 1M NaOH solution	First measure 7 days, then subsequence measure at28 and 56 days then at 3,6,9 and 12 months

To access the expansion range, although the concrete prism method is the most accurate and effective way to recognize the reactivity of aggregate but due to its long duration, for short time experiments, scientists prefer to use accelerated mortar bar test (AMBT) for determining the reactivity of aggregate.

2.6.2 ACR Test Methods for Evaluating Aggregate Reactivity

Using the presentation methods for ACR is ineffective to stop the reaction, so the safest way to deal with ACR is to identify reactive aggregate. Using ASTM C 1105-08, ASTM C 586-11, AASHTO PP65-11 and AAR-5 contribute to find the alkali-carbonate reactivity of an aggregate.

2.6.2.1 ASTM C 1105-08 (Test Method for Length Change of Concrete Due to Alkali-Carbonate Rock Reaction)

This test method is used to assess the potential for expansion tendency of concrete exposed to alkali- carbonate reaction.

The result of this test method should be part of the decision for considering precautions for concrete. (Munn et. al., 2011) In this method, changing the length of the concrete prism which is treated by alkali- carbonate reaction, indicate the expansion of aggregate which was affected by alkali-carbonate reaction. In this test method if the expansion of concrete prism is greater than 0.025% at 6 month or 0.03% at 1 year, the aggregate must not be used in concrete(U.S. Department of Transportation, 2013).

2.6.2.2 ASTM C 586-11 (Test Method for Potential Alkali Reactivity of Carbonate Rocks as Concrete Aggregates (Rock-Cylinder Method))

This test method is known as rapid indicator of potential expansive reactivity of carbonate rock. In this method, the researcher measure the expansion carbonate rock which is immersed in sodium hydroxide (NaOH) at normal room temperature then the expansion indicate whether the rock is potentially reactive or not. . (Munn et. al., 2011)(U.S. Department of transportation, 2013)

2.6.2.3 AASHTO PP65-11

In this test, the content of lime (CaO), alumina (Al_2O_3) and magnesia (MgO) is tested. Two ranges will be identify, non- expansive aggregate and potentially expansive. If the aggregate identify as non-expansive, it never cause any deleterious expansion by ASR, and if the aggregate identify as potentially expansive, the aggregate must evaluate further. For further tests, two ways will employ, using ASTM C 1293 (concrete prism test) to determine the reactivity of alkali-carbonate and then using petrographic consider as first way and as second, using ASTM C 1105 will contribute to determine the reactivity of alkali- carbonate (Grattan-Bellew et al., 2010)

2.6.2.4 AAR-5 (CARBONATE AGGREGATE TESTING)

RILEM TC 191-ARP introduced AAR-5 test method for evaluating the potential of alkali-carbonate reaction. The potentially reactive carbonate will be recognizing by two ways in this test method. Employing petrographic examination and chemical test is the first way and for the second way, using ultra accelerated mortar bar (ASTM C 1260 or AAR-2) can be mentioned (Sims & Nixon, 2003).

Table 2.3: ACR test methods

Test method	Test type	Test duration
ASTM 1105 (Concrete bar)	Concrete bars	measure the length3rd month, 6th month and 12th month
ASTM 586 (Rock cylinder)	Rock cylinder	First measure 7 days, then subsequence measure at 14,21,28 days then3,6, and 12 months
AAR-5	Two ways 1. Chemical test 2. Accelerated mortar bar test	14 days

2.6.3 Field Performance of Aggregates

Using long term field performance contribute researcher to determine the reactivity of aggregates. This test method should fulfill some condition such as

- Petrographic analysis must be done on the aggregate.
- The concrete must be more than 10 years old.
- The w/c ratio must be specified.

This test method must be done by experienced personnel for finding the reactivity of aggregate.

2.6.4 Other Test Methods Assessing AAR

2.6.4.1 Scanning Electron Microscopy (SEM)

This test method is used for detecting ASR gel. In this test method concrete is fractured into the small specimens and then coated by Epoxy resin. The specimens are placed under the stereomicroscope to identify target area and color photographs of specimens.

2.7 Prevention Methods

To prevent alkali-silica reaction (ASR) in concrete, various ways is used include

- Using non-reactive material
- Reducing the amount of alkali in concrete
- Using SCM
- Using lithium based compounds

The effect of using these precautions on the concrete performance such as workability, heat evaluation, shrinkage and etc. must be checked.

As mentioned before, in present of sufficient moisture, sufficient alkali content and sufficient reactive aggregate, the ASR damage tend to start. Elimination of one these elements will contribute to prevent ASR damage, so the easiest ways to prevent the ASR damages are

1. Reduce the amount of reactive aggregate
2. Reduce the amount of alkalis

2.7.1 Using Non-reactive Aggregates

The first, most effective and obvious step to minimize the risk of ASR is to identify reactive aggregate and try not to use them in concrete. The aggregate with long history of no reactivity in concrete can make safe guard against ASR damages. As mentioned before specifying the reactivity of an aggregate require some test methods like using the combination of petrographic and ASTM C 1260 or using ASTM C 1293.

Using non-reactive aggregate in concrete is not practical and economical because: (U.S. Department of transportation, 2013), (Munn et. al., 2011)

- Non- reactive materials are not available everywhere and must be transported over long distance to construction site
- Using non-reactive material will have an impact on environment
- The results of laboratory tests for reactivity of material are not 100% trustable.

2.7.2 Controlling the Alkali – Content of constituents

In the presence of higher alkali content, the concrete experiences more expansion therefore the alkali content in concrete should be less than certain limit value in order to minimize the risk of ASR expansion;. This value is varies according to the types of aggregates however still there is no standard international agreement for allowable amount of alkali content in concrete. Nixon and Sims (U.S. Department of transportation, 2013) suggests that the maximum allowable alkali contents should be between 2.5 and 4.5 kg/ m^3 Na_2O_e , where American Standards declared the alkali content of concrete must be lower than 0.6% and on the other hand, Canadian Standard, specified the amount of maximum permissible alkali for different level of prevention in 2000.

Table 2.4: Alkali Limit for Different Levels Required for of Prevention. (Canadian Standards, 2000)

Level of prevention required	**Alkali limit (kg/ m^3)**
Mild	3
Moderate	2.4
Strong	1.8
Exceptional	1.8+ SCM

2.7.3 Using SCMs

Several studies has been carried out on the effect of supplementary cementing materials (SCM) (Thomas, 2011).Several conclusion observed from these studies, using sufficient amount of SCM is one of the most effective ways for Munn et. al. the risk of ASR. SCMs can be added to concrete in order to reduce the cost of concrete, enhance the concrete's properties and reduce the risk of ASR. SCMs include pozzolans and slags (ggbs). The amount of SCMs varies due to (Gillott, 1995)(Li et al., 2000)(Thomas, 2011) :

- Amount of reactive aggregates
- Exposure conditions of concrete
- The alkali content in cement
- The alkali content of SCM
- The CaO/Sio_2 of SCM

Different test methods are used for determining the amount of SCM in concrete. ASTM C 1567 and ASTM C 1293 have been observed to be preferred more in the recent studies when compared to ASTM C 441 and ASTM C 227. In ASTM C 441, mortar bars made by Pyrex are stored in 38℃ for 14 to 56 days. This method is no longer widely used due to the nature of reactive aggregates. Thomas et. al.(Thomas et al., 2011) stated the level required of different type of SCMs, which may be exceeded under exceptional conditions (e.g. high alkali-availability in concrete, for critical structures or when extremely reactive aggregate are used.)

Table 2.5: the level required of different type of SCMs (Thomas et al., 2011)

Type of SCM	**Level required (%)**
Low- calcium fly ash	20-30
Moderate calcium fly ash	25-35
High calcium fly ash	40-60
Silica fume	8-25
Slag	35-65
Metakaolin	10-20

SCM reduce the alkalis in concrete pore solution and then contribute to reduce the expansion of concrete. Thomas (Thomas, 1996) and Thomas and Bleszynski (Thomas et. al, 2011) stated that using SCMs contribute to reduce the concentration of alkali- hydroxides in concrete so as a result reduce the expansion (Thomas, 2011). The reduction of pore solution alkalinity by SCMs depends on composition of C-S-H. Bhatty and Greening (Thomas, 2011) stated that for C-S-H with low Ca/Si ratio in comparison with high Ca/Si ratio, can be able to maintain more alkali.

Among all SCMs, those low in alkali and Calcium are the most effective in reducing the alkalinity, low calcium fly ash is a good sample of those material (Hayman et al., 2010). For reducing the expansion, more than 30% of low- calcium fly ash must be used.

2.7.4 Using Lithium Based Compounds

McCoy and Caldwell in 1951 for the first time explained the effect of lithium in mortar and concrete, and then several studies have been carried out on the effect of lithium. Feng et. al. (Feng et al., 2005) has reviewed preview studies and has reported that, the lithium salt reacts with reactive silica and form insoluble lithium silicate. The lithium silicate covers the reactive aggregate, so it protects the aggregate from alkali hydroxides attack.

The amount of lithium required to control the expansion is varies, depending the form of lithium, test methods and the reactivity of aggregates. (Munn, 2011)(Hayman et al., 2010) (U.S. Department of transportation, 2013)

Among all nitrate compounds, Lithium nitrate ($LiNO_3$) is considered to be the most efficient form for preventing ASR. According to function of this material, lithium nitrate called “ASR-suppressing admixture” in North America. (Munn et. al., 2011)(Hayman et al., 2010) (U.S. Department of Transportation, 2013)

2.7.5 Precaution Against External Moisture

In order to minimize the external moisture, some barriers are used to protect the concrete surface against external water but relying on these barriers for protecting against ASR damages are not recommended as permanent solution (Munn et. al., 2011)(Hayman et al., 2010).

2.8 ASR Test Methods for Evaluating Preventive Measures

As mentioned before, using lithium compound and SCM can contribute to prevent ASR. Test methods such as ASTM C 441, ASTM C 1567, ASTM C 1293, are the most common test methods to evaluate preventing measurement, among these ASTM C 1567 is determined as the most accurate and useful method among other test methods. (Munn et. al., 2011)(U.S. Department of transportation, 2013)

2.8.1 ASTM C 1567 (Standard Test Method for Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method))

ASTM C 1567 used to evaluate the use of SCMS. The condition of this test method is similar to ASTM C 1260 (U.S. Department of Transportation, 2013). In this test method, mortar bars are immersed in 1 N NaOH solution for 14 days then after that, the length measurement must be done. If the expansion is less than 0.10%, the aggregate will be non- reactive.

2.9 Remedial Actions to be taken for damaged structures

In the cases where results of site or laboratory investigation indicate the existence of alkali aggregate reaction, monitoring may be carried out and may be determined the type of remedial action that will be done for concrete structure.

Remedial actions include: (Munn et. al., 2011) (U.S. Department of Transportation, 2013)

- Limiting moisture ingress
- Chemical treatment
- Physical restrain
- Slot cutting
- Replacement

2.9.1 Limiting Moisture Ingress

Using drainage of concrete components which affected by AAR help the concrete element to reduce the AAR, so the water could be drained out of structure rather than on to the structure with drainaging. Using Siloxanes contribute the concrete elements to evaporate the water in concrete and makes them dry.

Flexible moisture proof members with changing in volume can contribute the members AAR affected to prevent further deteriorate damages. (Fournier & Berube, 2000) (Hayman et al., 2010)

2.9.2 Chemical Treatment

As mentioned before, lithium can prevent ASR. Using the lithium salt on the surface of ASR affected member or even injecting of lithium in bridge decks influenced by ASR can be a remedial measures against ASR. This process is not economical and practical for most of the cases, due to its hard and expensive procedure. (Fournier & Berube, 2000)

2.9.3 Physical Restraints

Using strap, steel plates, beams, composite beam and bolt reinforce the ASR affected member and provide sufficient structural strengthening. Injection of cement grout or epoxy resin can provide sufficient structural strengthening. (Fournier & Berube, 2000)(Munn et. al., 2011) (U.S. Department of transportation, 2013)

2.9.4 Slot Cutting

This process is used for gravity dams which are affected by ASR in order to modify and relief the stress, but using this process may cause increasing the expansion rate and movement after cutting. Using this remedial measure is not advisable because it is so expensive and often finds the temporary solution. (Fournier & Berube, 2000)(Munn et. al., 2011)(U.S. Department of Transportation, 2013)

2.9.5 Replacement

Although replacement of alkali aggregate reaction affected structures, is the safest remedial measure for ASR affected concrete members, but it is not economical movement. (Fournier & Berube, 2000)(Munn et. al., 2011)(U.S. Department of Transportation, 2013)

2.10 Geology of Cyprus and Characteristics of Rocks

Cyprus is located on Eurasian plate and southern border of Anatolian plate. Cyprus with a surface area of 9251 km^2 is the third largest Mediterranean island. This Island is divided into four geological bed rock units:

- The Kyrenia zone (Beşparmak ranges)
- The Trodos zone (or Trodos Ophiolite complex)
- The Mamonia zone
- The Circum zone Sedimentary Succession.

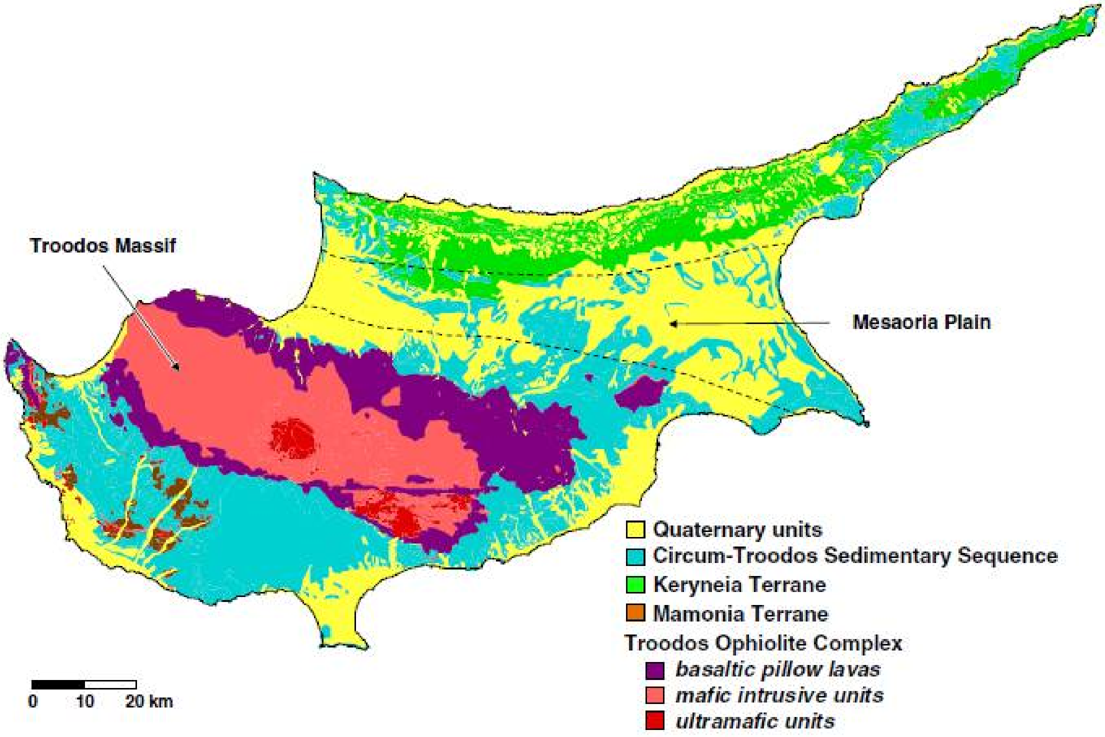

Figure 2.4: Main geological zone of Cyprus (Cohen et al., 2012)

2.10.1 Kyrenia Zone

Kyrenia zone (Beşparmak or pentadaktylos range) which is located in northern part of Cyprus is formed with three main geological formations:

- Allochthonous Dhikomo
- Sykhari

- Hilarion

Allochthonous Dhikomo consists of limestones with grey and green phyllites layers. The Sykhari consist of massive dolomitic limestones and the Hilarion is composed of low degree of metamorphism limestones (Cohen et al., 2012).

2.10.2 Trodos Zone

The Trodos zone located in the central part of island so it forms the core of Cyprus. This zone has a crucial role for water budget of island due to the type of rocks which are good aquifers for their fracturing (for e.g. sheeted dykes, diabase and gabbros) (Cohen et al., 2012).

2.10.3 Mamonia Zone

The Mamonia zone is composited by igneous, sedimentary and metamorphic rock. In this zone, earthquake has played significant role (Cohen et al., 2012).

2.10.4 Sedimentry Zone

The sedimentary zone is composited by sedimentary rocks. These types of rocks are the main sources of construction industry. The main industrial minerals included gypsum, brick, clays, chalks, and building stones (Cohen et al., 2012).

2.11 Cyprus Aggregates

Aggregate plays very important roles in construction industries. Reinforced concrete is the most widely used construction material; sand and gravel are two key component of concrete. Naturally in South Cyprus eroding the rocks from the river from Trodos Mountain contribute the construction industries to have aggregates. These aggregates such as gabbro, diabase, harzburgite etc. are normally made of Ophiolotic rocks. As mentioned in Table 1 (Potentially alkali- reactive rocks and mineral phases), Gabbros and Diabase are potentially reactive.

Another source of aggregate in Cyprus is the limestone comes from Kyrenia zone (Beşparmak rang), aggregates (recrystallized dolomitic limestone) from this range are an excellent source for crushed aggregates due to the Physical and mechanical properties of Kyrenia range’s aggregates.

According to Salihoğlu and his Colleague (Salihoğlu et al, 2014) researches, in north Cyprus, there are some quarries to get the aggregate. Table below shows the number of quarries in north Cyprus.

Table 2.6: Quarries in Cyprus (Salihoğlu et al, 2014)

Types of aggregates	**Total number of quarries**	**Active quarries**
Crushed stone	19	16
River	1	1
Gypsum	3	2
Building block	10	7
Total	54	36

The chamber of mining- metallurgical and geological engineers of TRNC on 2014 did some analyses on the aggregates from North Cyprus and specified the properties of different types of aggregates there. Table.7 shows the result of analyses.

Table 2.7: Properties of North Cyprus aggregate

LAB NO.	**The land where the rock sample was taken**	**MgO %**	**Al_2O_3 %**	**SiO_2 %**	**CaO %**	**Fe_2O_3 %**	**The amount of CaO% in each Kg of rock**
D-33638	Akdag Tepe, Limestone(Sandy)	1.0	2.8	11.8	44.5	1.7	65.6
D-33639	South of Erdemli inside the T. Bozkort quarry (Building stone)- Limestone	0.6	1.0	4.1	51.2	0.4	86.8
D-33640	Ahmet Ersoy Quarry located on the north east Akcicek- Crystallized dollometic limestone	3.4	0.1	0.2	51.2	0.1	94.2
D-33641	Soyer- Arpalikli crushed aggregate quarry located at east of Girne- Bogazi- Dolometic Limestone	18.6	0.1	0.2	33.2	0.1	70.4
D-33642	Tile quarry located south of Beylerbeyi- Limestone	0.6	0.1	0.3	54.6	<0.1	97.8
D-33643	Inside of Tile quarry located south of Beylerbeyi- Limstone	0.7	0.2	0.7	54	0.1	96.6
D-33644	The crushed aggregate of Kel. Ahmet located north west of Degirmenlik- dolomitic limestone	19.8	0.2	0.5	31.3	0.1	67.1
D-33645	The crushed aggregate quarry (Eastern part) of department of highways located north of Degirmenlik- crystallized dolomitic limestone	7.8	1.1	3.5	43	0.2	78.2
D-33646	The quarry located 6-7 Km east of Kaatara casyle, 30 m into the south of quarry- Marblized limestone	0.6	0.1	0.4	54.2	0.1	97.5
D-33647	The marble quarry located north west of Agillar village, 7-8 Km west of Kuntara transmission facilities- Marblized Limestone	0.5	0.1	0.5	54.5	<0.1	97.6

Sand is also produced from Calcarenite in Nicosia. Calcarenite was used in defensive area like Venetian walls of Nicosia, public building, Mosques and churches. Recently this type of rock used for marine works.

2.12 Cements in Cyprus

There are different types of cements available in the markets in North Cyprus which are mostly classified as blended cements aiming to meet the requirements for available soil characteristics and environmental conditions example the soil is clayey soil with presents of salts in it. The use of these cements in TRNC is also beneficial, considering the need of producing a concrete with low permeability, the one that form of denser micro structure with the adequate curing of the concrete that will be more resistant to all kinds of durability problem.

2.13 Blended Cements:

Blended cements are manufactured by adding or grinding ordinary Portland cement with other cementitious materials at given proportions in order to produce cements with special properties. (Bye, 1999)

Cementitious materials are materials that are as fine or less as ordinary as Portland cement that are mix with ordinary cement in a specified proportion to form blended cements (Bye, 1999). Examples of cementitious materials are; Ground granulated blast furnace slag, pozzolanas and Fillers.

The name of cements that are observed to be available in the market of TRNC and their principle properties are mentioned below:

I. CEMIII/A42,5N,EN197-1:2000 (Blast Furnace- Sulphate Resistant Cement)

II. CEM IV/B (P) 325 R, TS-EN 197-1 (Pozzolanic Cement)

III. CEM II/B-M(S-L) 32,5R, TS-EN 197-1 (Portland Composite Cement)

IV. TS 21/BPC 525R/85 (White Cement)

I. CEMIII/A42,5N,EN197-1:2000 (Blast Furnace-Sulphate Resistant)

This type of cement from the name it contains ground granulated blast furnace slag (GGBFS) grinded with ordinary Portland cement. GGBFS is a waste product of industrial manufacture of pig iron, it's a mixture of silica, alumina and lime, which are the oxides that made Portland cement but at different proportions.

3-Classes of Portland blast furnace cement were mentioned in EN 197-1 ; blast furnace cement III/A, III/B and III/C all of which the percentage of filler by their total mass should not exceed 5% with a percentages of GGBS replacement by their total mass below;

Class III/A	36% - 65%
Class III/B	66% - 80%
Class III/C	81% - 95%

The fineness of GGBFS is usually above 350m^2/kg. Using cement containing slag increases workability of fresh concrete, making it more mobile and cohesive with low heat generation that results in low peak temperature, also produces concrete with denser microstructure with long term strength and durability more than ordinary Portland cement due to filled spaces with calcium silicate hydrate (C-S-H) from reaction of silica (SiO_3) and calcium hydroxide ($Ca(OH)_2$) (Bye, 1999).

Using GGBS in cement reduces concrete permeability of about one hundred (100) times, significant reduction in concrete diffusivity that reduces the injections of harmful chemicals to the concrete like chlorides solution, carbonic acid (HCO_3) from carbon dioxide (CO_2) (Bye, 1999).

Table 2.8: Typical chemical composition and fineness requirement of cement type III (Lara, 2008)

ASTM cement type	**Typical Chemical composition (%)**				**Fineness requirement(m^2/kg)**
	C_3S	**C_2S**	**C_3A**	**C_4AF**	
III	55-65	5-25	5-12	5-12	390-644

Figure 2.5: Cyprus Blast Furnace- Sulphate Resistance cement (CEMIII/A 42.5N, EN 197-1:2000)

II. CEM IV/B (P) 325 R, TS-EN 197-1 (Pozzolanic Cement)

According to the EN- 197-1, Portland cement type II is called high early strength. Due to high C_3S and higher fineness in comparison with the other types of cement, cement type III is characterized for reaching high strength in early ages. (Lamond & Pielert, 2006).

It contents both fly-ash and silica fume with a replacement from 36% to 55% of the total mass of the Cement.

Pozzolanas: According ASTM C 593 Pozzolana is a siliceous or siliceous and aluminous material which itself only possessed little or no cementitious value but in finely divided, in the presence of moisture and at normal temperature chemically react with calcium hydroxide ($Ca(OH)_2$) to form other compounds possessing cementitious properties. They are cheaper than the ordinary Portland cement they replace.

Use of pozzolanas in concrete increases the resistance to alkali-aggregate reaction, as a result of reducing the alkalis in concrete pore solution and then in this way, a reduction in the expansion of concrete is provided. (Thomas, 2011)

Fly ash: Fly-ash is a precipitated ash mechanically or electrostatically from the exhaust gases of coal-fired power stations. Fly ash is the most common artificial pozzolanas, it has particles that are spherical in shape which is advantage to the mix-water requirement, and it has higher fineness of 250-600m^2/kg and a diameter of 100 micro meters.

The most important property of fly ash is reducing water demand in a concrete mix which is due to spherical nature of its particles, since the less the water cement ratio the higher the strength and less permeability of the concrete. (Bye, 1999)

Silica fume: Silica fume is waste product of the manufacture of silicon and ferrosilicon alloys from high purity quartz and coal. It has very high fineness of about 20000m^2/kg and a very low bulk density, these properties provide better parking effect to concrete with silica fume when it enters and full empty spaces of cement particles, and a small amount is required in mix due to its high reactivity with $Ca(OH)_2$. (Bye, 1999)

Table 2.9: Typical chemical composition and fineness requirement of cement type IV(Lara, 2008)

ASTM cement type	**Typical Chemical composition (%)**				**Fineness requirement(m^2/kg)**
	C_3S	**C_2S**	**C_3A**	**C_4AF**	
IV	45-70	10-30	0-15	6-18	250-600

Figure 2.6: Cyprus Pozzolanic Cement (CEM IV/B (P) 325 R, TS-EN 197-1)

III. CEM II/B-M(S-L) 32,5R, TS-EN 197-1 (Portland Composite Cement)

According to the EN 197-1, Portland cement type II is called moderate sulfate resistance or moderate heat of hydration. It contents fly-ash, silica fume, fly ash, bunt-shale and lime stone replacement from 21% to 35% percent of the total mass of the Cement. The heat of hydration of this type of cement is low due to content of C_3A and C_4AF, and the content of C_3S contributes the cement to have a good resistance against sulfate attack. This type of cement meet the chemical requirement of cement type I (OPC) so in the absence of OPC, cement type II can replace OPC.(Lamond & Pielert, 2006)

Table 2.10: Typical chemical composition and fineness requirement of cement type II (Lara, 2008)

ASTM cement type	**Typical Chemical composition (%)**				**Fineness requirement(m^2/kg)**
	C_3S	**C_2S**	**C_3A**	**C_4AF**	
II	35-60	15-35	0-8	6-18	280-380

Figure 2.7: Cyprus Portland Composite Cement (TS-EN 197-1, CEM II/B-M(S-L) 32,5R)

IV. TS 21/BPC 525R/85 (White Cement)

This type of cement is similar to ordinary Portland cement except for its high degree of whiteness and due to this property, it’s more expansive. It is mainly used for architectural purposes. To have this type cement, the content of Fe_2O_3 must be less than 0.5 %. It usually uses in pre-cast concrete productions so it needs to meet the high early strength specification like Portland cement type III. White cement is made from china clay (Bye, 1999) which contains little iron oxide and manganese oxide, together with chalk or limestone free from impurities, which could affect the color. Special precaution is taken during the preparation in order to avoid contamination of the cement.

Figure 2.8: Cyprus White Cement (TS 21/BPC 525R/85)

CHAPTER 3

METHODOLOGY AND MATERIALS

3.1 General Concepts

After surveying the relevant literature, considering the Cyprus conditions and restrictions such as availability of limited quarries, appropriate materials and test method was chosen to be used in this study.

3.2 Selection of Materials

3.2.1 Cement

Among four available cement types, CEM II / B-M have been observed to be preferred in the recent construction's site in Cyprus due to its moderate heat of hydration and high sulfate resistance and moderate heat of hydration so this type cement is suitable for hot climate regions such as Cyprus.

For this study CEM II / B-M was chosen to observe the potential of typical cements use in Cyprus constructions to initiate the alkali aggregate reaction. CEM I (OPC) is the other cement was used in this thesis, in order to verify the effect of SCMs presence on the result, as a control set of expansion of different batches of aggregate.

According to EN 197-1, CEM II / B-M consist of 65-79% (total mass of cement) clinker and 21-35% (total mass of cement) supplementary cementing materials (SCMs), and CEM I (OPC) consist of 95-100% (total mass of cement) clinker, therefore in this study CEM I (OPC) was used to determine the influence of SCMs presence on the AAR occurrence likelihood, as a control set of expansion of different batches of aggregates and cements.

Table 3.1: Chemical composition of used cement according to TS-EN 197-1

	Al_2O_3	Fe_2O_3	SiO_2	CaO	Na_2O_{eq}
CEM II/B-M	6.41	2.32	24.2	58.38	0.6
CEM I	5	3	21	62	0.6

3.2.2. Aggregates

Aggregate from the quarries from both North and South Cyprus were taken into consideration in order to assess their alkali reactivity and suitability for using in concrete. As mentioned before Cyprus is divided into four geological bed rock units:

- The Kyrenia zone (Beşparmak Range)
- The Trodos zone (or Trodos Ophiolite complex)
- The Mamonia zone
- The Circum zone Sedimentary Succession.

In previous studies (Nixon P.J & Sims I, 1992), (Idorn, 1997) the potential of South Cyprus aggregate to initiate the alkali aggregate reaction was discussed, In the 9th international conference on alkali-aggregate reaction in concrete, Nixon and sims (Nixon P.J & Sims I, 1992) expressed the present of alkali aggregate reaction in Cyprus but there were no experimental data-set on the level of reactivity of South Cyprus aggregates and there is no available data found for status of Cyprus aggregate against alkali aggregate reaction. Therefore, this is the first time such a study was carried out in North Cyprus.

For the south Cyprus aggregate, diabase from Pirga quarry of Trodos Mountain was the only available choice.

For the North Cyprus aggregate, as Wu Ding-yan and Fang Kun-Hy (Wu Ding-yan & Fang Kun-Hy, 2004) suggested that the alkali-silica reaction can still initiate even alongside the rocks with low contents of SiO_2. Considering this information along with the data provided in table 2-7, the studies carried out for this thesis are focused on two mines that might provide the aggregate having significance for this study. Aggregates from the crushed aggregate of Ahmet Topal

Quarry located North West of Değirmenlik- Dolomitic limestone were chosen for alkali carbonate experiment for having high amount of MgO to initiate dedolomitision. On the other hand, the crushed aggregates of quarry (Eastern part) of Department of Highways located north of Değirmenlik - Crystallized dolomitic limestone for having the highest amount of SiO_2 among the available quarries in North Cyprus were chosen for alkali silica reactivity experiment. From both Ahmet Topal Quarry and Değirmenlik Quarry, the aggregates were collected from different locations of each stockpile to have aggregates which represent all characteristics of quarry.

In figure 3-1, “Ahmet Topal ” quarry which was located in west of Değirmenlik can be seen, in figure 3-2, two pictures from “Pirga” quarry can be seen and in figure 3-3, the quarry of Department of Highways located north of Değirmenlik can be seen.

Figure 3.1: “Ahmet Topal ” Quarry

Figure 3.2: “Pirga” Quarry of Trodos Mountain

Figure 3.3: Quarry of Department of Highways located north of Değirmenlik

3.3. Selection of Test Methods

After surveying of relevant literature and standards, AAR-2 (ASTM C 1260 (ultra-accelerated mortar-bar testing)) and AAR-5(Rapid preliminary screening test for carbonate aggregates) were selected to be used throughout this study, due to their clearly defined expansion limits and viable procedures, along with the relatively short duration in which they propose to provide the results.

3.3.1. Equipments and Tools Needed for AAR-2 and AAR-5

3.3.1.1 Sieves

A set of sieve contain the sieve No.4, 8, 16, 30, 50 and 100. (4.75, 2.36, 1.18, 0.6, 0.3, 0.15 mm) for AAR-2 and a set of sieve contain the sieve No.4, 8 for AAR-5

Figure 3.4: sieves 4.75, 2.36, 1.18, 0.6, 0.3, 0.15 mm (AAR-2) and sieve 4, 8 mm (AAR-5) and the sieve shaker used in this study

3.3.3.2 Balance

A balance capable of weighting 3000 g with the accuracy of 1g was used throughout the study.

3.3.3.3 Measuring cylinders

Measuring cylinders graduated in ml, with the capacity of 900 ml.

3.3.3.4 Mixer and mixing bowl

Automatic mixer and its bowl were used (with EN. 196-1 mode of mixing)

Figure 3.5: Automatic mixer (EN 196-1) used in this study

3.3.3.5 Mold

AS AAR-2 stated, at least 3 molds with a normal length of 285 mm and cross section of 25mm × 25 mm, the end plates of mold should have stainless steel pins of 6mm diameter and 20 mm length for measuring the length change for using in AAR-2 method and as AAR-5 stated, at least 3 molds with a normal length of 160 mm and cross section of 40 mm × 40 mm, the end plates of mold should have stainless steel pins of 6mm diameter and 20 mm length for measuring the length change.

Figure 3.6: Mold (25* 25*285 mm) used in AAR-2 and Mold (40*40*160) used in AAR-5

3.3.3.6 Tamper

Tamper should be non- absorbent steel, its face should be flat.

3.3.3.7 Length Comparator

Length comparator is an apparatus to measure the length of specimens rapidly; with an accuracy of ± 2.5 µm.

Figure 3.7: Length Comparator

3.3.3.8 Container

The container must be made of material resist to corrosion by solution of NaOH at temperature of 80℃ for a long time and must be provided with lid. In this study Pyrex container and cyramic lid on it used due to their high resistant against heat and NaOH solution.

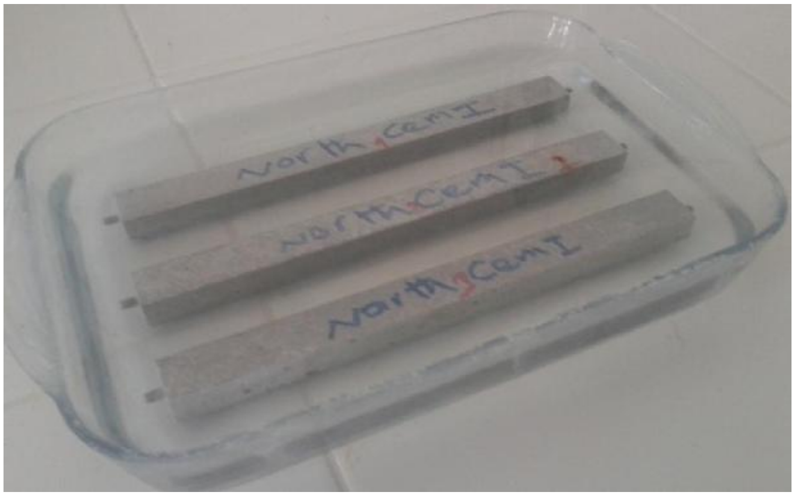

Figure 3.8: Pyrex containers used in this study

3.3.3.9 Oven

ELE drying oven was used to expose the mortar specimens. The heater was equipped with calibrated dial indicator and a thermometer. The temperature range of oven is 40 to 200℃.

Figure 3.9: ELE Oven used throughout this study

3.3.3.10 Vibration Table

Using vibration table to having more compacted mortar bars.

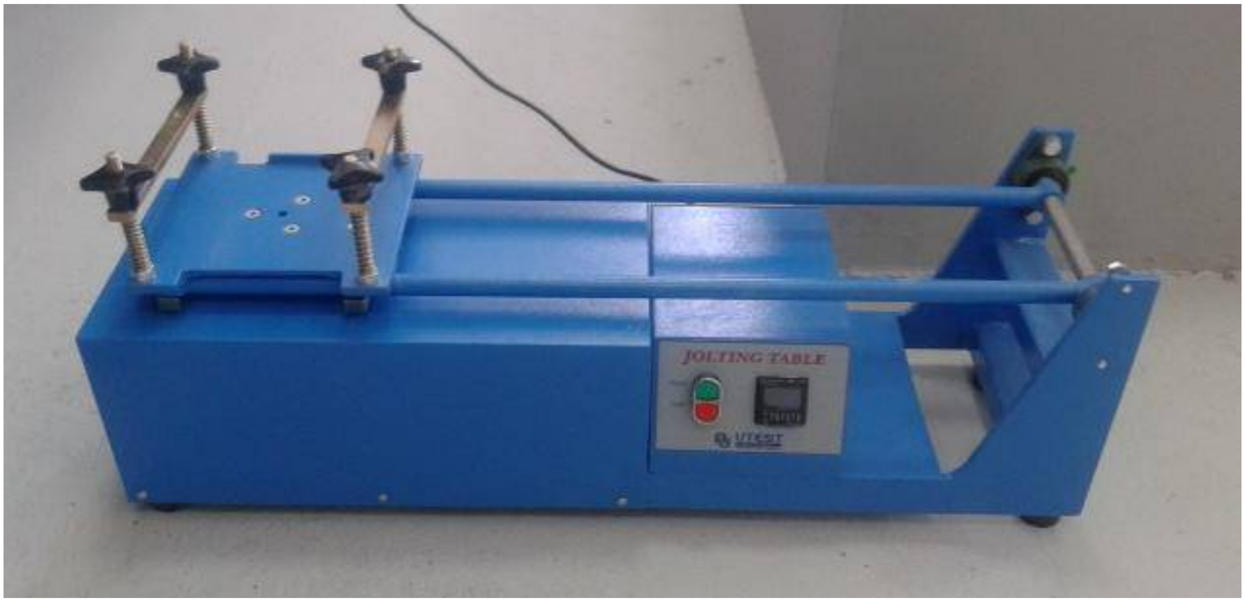

Figure 3.10: Vibration table used in the compaction of the samples prepared for this study

3.3.2 Material used in AAR-2 and AAR-5

3.3.2.1 Water

Drinking water for mortar preparation and distilled water for solution preparation were used.

3.3.2.3 Sodium Hydroxide Solution

For both AAR-2 and AAR-5, 1 N of sodium hydroxide solution is required. To prepare 1 N of sodium hydroxide solution, 40 g of NaOH must dissolve in 900 mL of water and then diluted with additional 100 mL of distilled water. To immerse the mortar bars in sodium hydroxide solution, the ratio of volume proportion of sodium hydroxide to mortar bars in storage container should be 4/1. According to the standard the volume of mortar bar is 184 mL therefore 2208 mL sodium hydroxide solution is required, for each batch for 3 mortar bars

Table below shows weights of constituents required for preparation of NaOH solution for the exposure of each 3 bars.

Table 3.2: Constituents of required NaOH solution

Constituents	
NaOH (g)	88.32
Water (mL)	1987.2
Distilled water (mL)	220.8

3.3.3 Brief Summary of Both AAR-2 and AAR-5 Test Procedures

3.3.3.1 AAR-2 (ASTM C 1260 (Ultra-Accelerated Mortar-Bar Testing))

AAR-2 and ASTM C 1260 have parallel procedures, with identical exposure conditions and identical result interpretation methods, the only difference between this two test methods is that, In AAR-2, three set of sieves can be used.

The scope of this test method is to determine rapidly the potential alkali- reactivity of silica aggregate through the evaluation of expansion of immersed mortar bars in 1N NaOH solution. According to the standard, for each batches three samples is needed.

3.3.3.1.1 Procedure

3.3.3.1.1.1 Preparation of the Aggregate Sample

Weights of constituents needed for each batch of 3 mortar bars according to the AAR-2 was mentioned in table below.

Table 3.3: Constituents of mortar bars defined in AAR-2 (RILEM TC 191-ARP, 2000)

Constituents	
Cement (g)	400
Fine aggregate (g)	900
Water (g)	188
Water/cement ratio	0.47

Fine aggregates from each source (North and South Cyprus) were graded as shown in table below.

Table 3.4: Fine aggregate grading defined in AAR-2 (RILEM TC 191-ARP, 2000)

Sieve size		**Mass%**	**Weight (g)**
Passing	**Retained on**		
4.75 mm (No.4)	2.36mm (No.8)	10	90
2.36mm (No.8)	1.18mm (No.16)	25	225
1.18mm (No.16)	600µm (No.30)	25	225
600µm (No.30)	300µm (No.50)	25	225
300µm (No.50)	150µm (No.100)	15	135

3.3.3.1.1.2 Producing Mortar Bars

1. Initially according to the grading, the sieved aggregates from both North and South source were weighed.

Figure 3.11: Sieved aggregate according to AAR-2

2. With the help of automatic mixer, and considering the cement and aggregate type, mixing process of mortar batch was done according to European Norms.

Figure 3.12: Cement water and aggregate

3. After mixing, each mold was filled with two equal layers and then compacted.

Figure 3.13: Molding of North Cyprus aggregate and CEM I and II

4. Next, each mold was placed in moist cabinet at room temperature and 90% humidity for 24 hours.

Figure 3.14: placing the mortar bars in moist cabinet

5. The mortar bars from molds were removed.

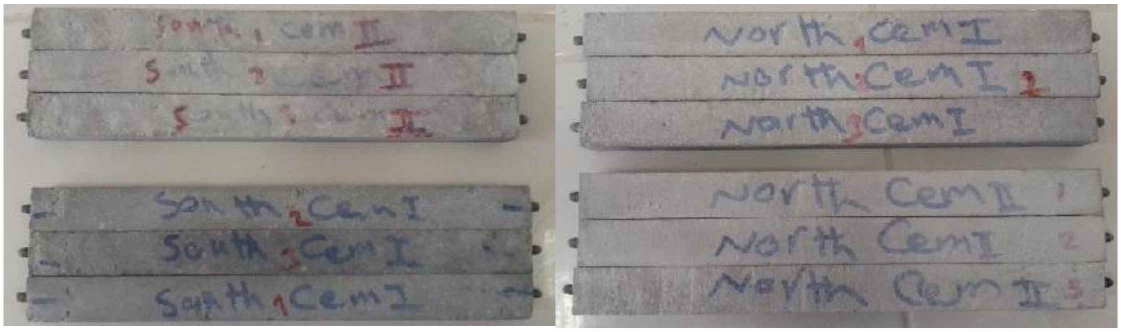

Figure 3.15: Demolded bars

6. The mortar bars are immersed in container with distilled water, sealed carefully and placed in oven (with 80℃) for 24 hours.
7. After 24 hours, the mortars bars were removed from the water container and were dried with the towel and within 15 sec after removing from water, their length were measured(L_0).

Figure 3.16: Length measurement of bar with the help of length comparator

8. When the measurement was done, the mortar bars were immersed in 1N sodium hydroxide for 14 days. During these 14 days, 5 comparator reading (Ln) (at 3rd, 6th, 9th, 12th and 14th days of experiment) were done at same time each day.

3.3.3.1.1.3 Expansion

The expansion of each specimen is determined by calculating the change in length of specimens at each period (Ln) and the zero reading (L_0):

Length change, % = $\frac{Ln-L0}{Gauge\ length} \times 100$

(Gauge length =285 mm + (2× 10 (length of each pins)) = 305)

3.3.3.1.1.4 Interpretation of Results

According to the ASTM C1260 and AAR-2 (ultra-accelerated mortar-bar testing):

1. If the expansion of mortar bars during 14 days of experiment is less than 0.10%, then the aggregate is called innocuous.
2. If the expansion of mortar bars during 14 days of experiment is more than 0.20% then the aggregate is called potentially deleterious.
3. If the expansion is between 0.10% and 0.20% the aggregate is called potentially reactive material.

3.3.3.2 AAR-5 (Rapid Preliminary Screening Test for Carbonate Aggregates)

The scope of this test method is to determine rapidly the potential alkali- reactivity of Carbonat aggregate through the evaluation of expansion of immersed mortar bars in 1m NaOH solution. According to the standard, for each batches three samples is needed.

3.3.3.2.1 Procedure

3.3.3.2.1.1 Preparation of the Aggregate Sample

Weights of constituents needed for each batch of 3 mortar bars according to the AAR-5 was mentioned in table below.

Table 3.5: Constituents of mortar bars defined in AAR-5 (RILEM TC 191-ARP, 2005)

Constituents	
Cement (gr)	900
Fine aggregate (gr)	900
Water (gr)	290
Water/cement ratio	0.32

Table 3.6: Fine aggregate grading defined in AAR-5 (RILEM TC 191-ARP, 2005)

Sieve size		**Mass%**	**Weight (gr)**
Passing	**Retained on**		
4 mm	8 mm	100	900

3.3.3.2.1.2 Producing Mortar Bars

1. The sieved aggregates from both North and South source were weighed according to the grading.

Figure 3.17: Sieved aggregate (No.8,4)

2. According to the standard, the amount of Na_2O_{eq} of mortar should be 1.5% by mass of cement. Considering that both CEM II/B-M and CEM I (OPC) was used in this study, has 0.6% Na_2O_{eq} by mass of cement, 0.9% of Na_2O_{eq} is needed to reach 1.5%, therefore in addition to cement, water and fine aggregate, 8.64 gr of NaOH should be added in order to increase the alkali amount (Na_2O_{eq}) in each batches of mortar to 1.5 % by mass of cement.
3. With the help of automatic mixer, and cement and aggregate type, mixing process of mortar batch was done according to the European Norms.

Figure 3.18: Cement water and aggregates

4. After mixing, each mold was filled with two equal layers and then with the aid of vibrating table, the compaction process was done.

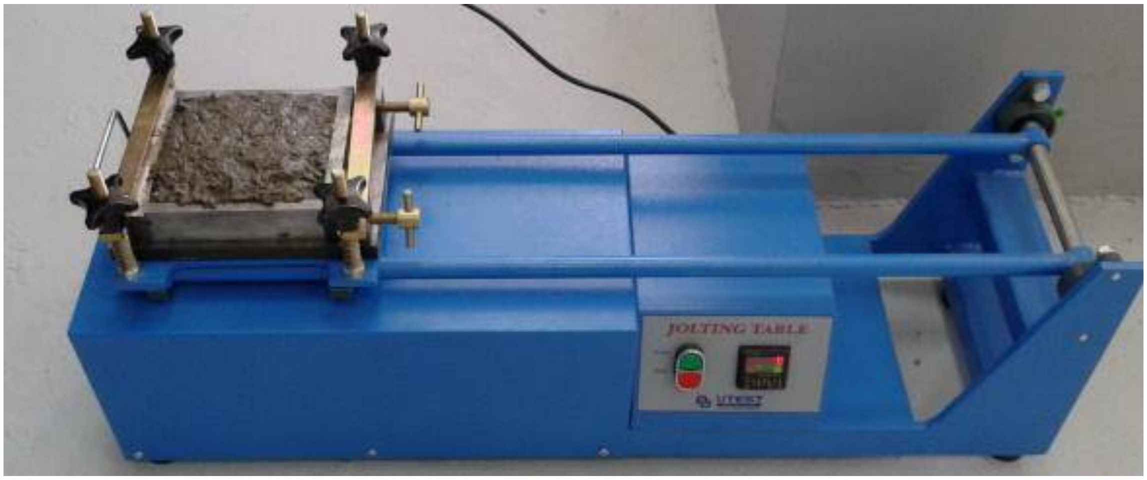

Figure 3.19: Compacting with vibration machine

5. Next, each mold was placed in moist cabinet oat room temperature and 90% humidity for 24 hours.

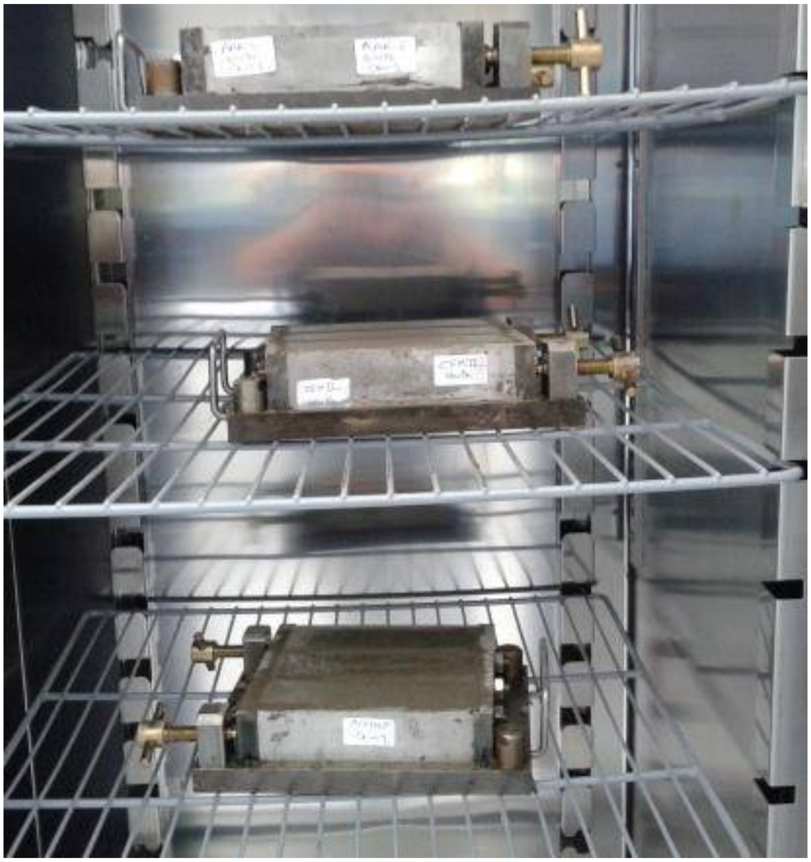

Figure 3.20: Placing the mortar bars in moist cabinet

6. The mortar bars from mold were removed.

Figure 3.21: Demolded bars

7. Immersed the mortar bars in container contains distilled water, sealed carefully and then samples were placed in oven (at 80°C) for 24 hours.
8. After 24 hours, the mortars bars were removed from the water container and were dried with the towel and within 15 sec after removing from water, their length length were measured(L_0).

Figure 3.22: Length measurement with the help of length comparator

9. When the measurement was done, mortar bars were immersed in 1N sodium hydroxide for 14 days. During these 14 days, 5 comparator reading (Ln) (at 3rd, 6th, 9th, 12th and 14th days of experiment) were done at same time each day.

3.3.3.2.1.3 Expansion

The expansion experienced by each specimen is determined by calculating the change in length of specimens at each period (Ln) and the zero reading (L_0):

Length change, % = $\frac{Ln-L0}{Gauge\ length} \times 100$

(Gauge length =160mm + (2× 10 (length of each pins)) =180)

3.3.3.2.1.4 Interpretation of Results

According to the AAR-5 (Rapid preliminary screening test for carbonate aggregates)

4. If the expansion of mortar bars during 14 days of experiment is less than 0.10%, then the aggregate is called innocuous.
5. If the expansion of mortar bars during 14 days of experiment is more than 0.20% then the aggregate is called potentially deleterious.
6. If the expansion is between 0.10% and 0.20% the aggregate is called potentially reactive material.

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 Results

4.1.1. General concept

After carrying out the experiments on both North and South Cyprus aggregates with cement Type I and cement Type II with the aid of AAR-2 (Ultra-Accelerated Mortar-Bar Testing) for testing the alkali silica aggregate and AAR-5(Carbonate Aggregate Testing) for testing the alkali carbonate aggregate, the results are as follow:

Table 4.1: Assigned name of each aggregate

Type of aggregate	Name
Crystallized dolomitic limestone (Degirmenlik Quarry)	North aggregate 1
Dolomitic limestone ("Ahmet Topal" Quarry)	North aggregate 2
Diabase (Pirga Quarry)	South aggregate 1

.

4.1.2. Results of Alkali Silica Reaction's Experiment (AAR-2)

Table 4.2: Length change (%) for alkali silica reaction (AAR-2) during 14 days, compared to L_0

		3rd day	**6th day**	**9th day**	**12th day**	**14th day**
North 1 and CEM II	St. Deviation	0.000213	0.000137	0.000324	0.000323	0.00034
	Mean	0.069938	0.099198	0.10037	0.111605	0.117018
North 1 and CEM I	St. Deviation	0.000387	0.00041	0.000188	0.000267	0.000247
	Mean	0.026914	0.019691	0.022346	0.030747	0.034461
South and CEM II	St. Deviation	0.001109	0.001382	0.002295	0.00204	0.002036
	Mean	0.048951	0.21392	0.250926	0.270186	0.279513
South and CEM I	St. Deviation	0.000377	0.000268	0.000236	0.000259	0.000279
	Mean	0.053333	0.058148	0.077469	0.081895	0.084487

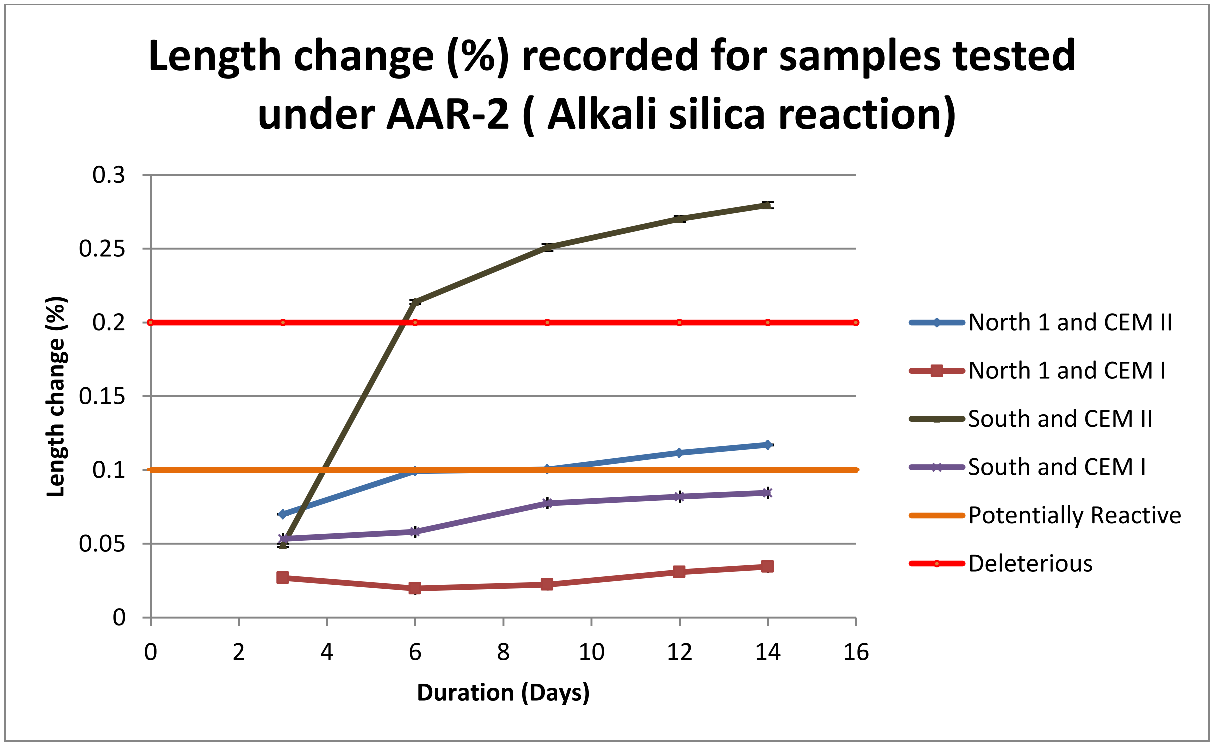

Figure 4.1: Length change (%) recorded for samples tested under AAR-2 (Alkali silica reaction) during 14 days

4.1.2. Results of Alkali Carbonate Reaction's Experiment (AAR-5)

Table 4.3: Length change (%) for alkali silica reaction (AAR-5) during 14 days, compared to L_0

		3rd day	**6th day**	**9th day**	**12th day**	**14th day**
North 2 and CEM II	St. Deviation	0.000909	0.001029	0.001024	0.001019	0.001006
	Mean	0.115494	0.134383	0.134877	0.135802	0.139407
North 2 and CEM I	St. Deviation	0.000402	9.05E-05	0.00056	0.00056	0.000563
	Mean	0.002778	0.026296	0.066605	0.068825	0.074452
South and CEM II	St. Deviation	0.000228	0.000253	0.000347	0.000394	0.00041
	Mean	0.06642	0.084938	0.099757	0.103681	0.107759
South and CEM I	St. Deviation	0.000481	0.000432	0.000428	0.000458	0.000452
	Mean	0.076173	0.061111	0.089691	0.094737	0.096254

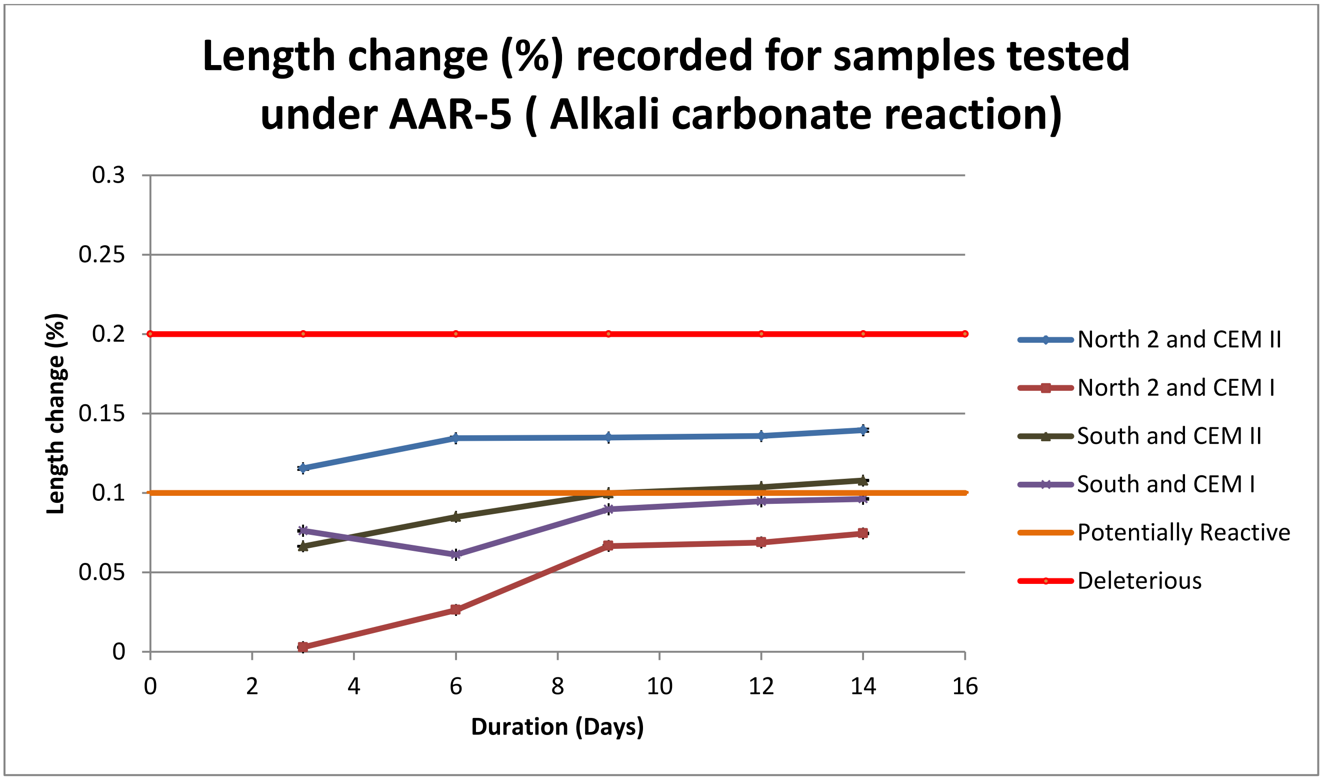

Figure 4.2: Length change (%) recorded for sample tested under AAR-5 (Alkali carbonate reaction) during 14 days

4.2 Discussions

As mentioned before, according to the AAR-2 (ultra-accelerated mortar-bar testing) for alkali silica reaction test and AAR-5(carbonate aggregate testing) for alkali carbonate reaction test, if the expansion during 14 days is less than 0.10%, the aggregate is accepted as innocuous, if the expansion is more than 0.20%, the aggregate is accepted as potentially deleterious expansion and if the expansion is between 0.10% and 0.20%, the aggregate is accepted as potentially reactive material. Therefore, considering the final results, the potential reactivity of each batch is given in table below:

Table 4.4: Potential alkali reactivity level of Cyprus aggregate

Batches	**Alkali Silica Reaction**
North aggregate 1 and CEM II	potentially reactive
North aggregate 1and CEM I	Innocuous
South aggregate 1 and CEM II	Deleterious
South aggregate 1 and CEM I	Innocuous

Batches	**Alkali Carbonate Reaction**
North aggregate 2 and CEM II	potentially reactive
North aggregate 2 and CEM I	innocuous
South aggregate 1 and CEM II	potentially reactive
South aggregate 1 and CEM I	innocuous

Therefore, considering the results from table above, using CEM II/B-M with both North aggregates and south aggregates has the potential to initiate the alkali aggregate reaction. Although CEM II/B-M has 21 to 35 % (total mass) supplementary cementing materials (SCM) and as mentioned in chapter two, using SCMs reduce the alkali in concrete pore solution and then contribute to reduce the expansion of concrete (Thomas, 1996), but in this study using CEM I as a control set, shows that, using CEM II/B-M can increase the potentiality of aggregate to initiate the alkali aggregate reaction.

As mentioned in chapter two, the precise amount of SCMs in order to risk of alkali aggregate reaction is still vague. In addition, Thomas (Thomas, 2011) stated that, the composition of C-S-H may have effect on SCMs and as Bhatty and Greeting (Thomas, 2011) suggest that, C-S-H alongside lower Ca/Si ratio can reduce the risk of alkali aggregate reaction in comparison to high Ca/Si ratio.

Therefore, according to these information and the data obtained from the experiments carried out throughout this study, using CEM I as a control set of CEM II/B-M, it is observed that;

- Although SCMs is known as a prevention method for alkali aggregate reaction, it is observed that cement alongside SCMs yielded to increase risk of alkali aggregate reaction.
- The above observation suggests the possibility that the composition of SCMs used in CEM II/B-M, might contain high Ca/Si ratio, which failed to prevent to initiate of alkali aggregate reaction.
- The likelihood for the occurrence of alkali aggregate reaction in South Cyprus was stated previously. The findings obtained in this study confirm the likelihood for the occurrence of alkali aggregate reaction in South Cyprus.
- For the North Cyprus aggregates, Dolomitic limestone from “Ahmet Topal Quarry” for alkali carbonate reaction and crystallized dolomitic limestone from “Değirmenlik Quarry” for alkali silica reaction were both potentially reactive aggregate to initiate alkali aggregate reaction in combination with CEM II/B-M. Therefore, special considerations must be taken into account while using them in manufacture of concrete used in reinforced concrete constructions.
- For comparing the results obtain in this study with the other researcher’s results, Research of Yuksel and his collogues (Yuksel et al., 2013) was considered as relevant, as they have also used CEM II 42.5 R in combination with crushed limestone according to AAR-2, therefore they stated that, the length change during 14 days was 0.125%, they suggest that the combination of crushed limestone in combination with CEM II will be potentially reactive. On the other hand, all the aggregates in combination with CEM II, in this study have potential to be reactive.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this study, experimental investigations are the concept of AAR in concrete. Alkali silica reaction and alkali carbonate reaction investigations were carried out in the Civil Engineering Laboratory of Near East University, on both North Cyprus (Crystallized dolomitic limestone for checking the ASR potentiality and Dolomitic limestone for checking the ACR potentiality) and South Cyprus aggregates (diabase) with CEM I alongside CEM II/B-M. The length change observed in each type of sample during 14 days exposed to AAR-2 and AAR-5 conditions was observed. A detailed literature survey was made in this study, there is no available data found for status of Cyprus aggregates reactivity against alkali aggregate reaction. Therefore, this is the first time such a study was carried out in North Cyprus.

The following conclusions are drawn;

1. Although CEM II/B-M has SCMs and SCMs is known to reduce the occurrence of the AAR, using CEM II/B-M increased the occurrence of AAR in all types of Cyprus aggregates in this study. This phenomenon is expected to happen due to two possible reasons:
   - Having an exceeded amount of SCMs,
   - Composition of SCMs used in CEM II/B-M, might contain high Ca/Si ratio.
2. As expected before, South Cyprus aggregate is potential to initiate alkali aggregate reaction. Therefore, mix of South Cyprus aggregate (Diabase) with CEM II/B-M is found to be the most deleterious among other batches (its length change is more than 0.20%, therefore it is deleterious).
3. Combination of North Cyprus aggregate with CEM II/B-M is potential to initiate alkali aggregate reaction. Their length change is more than 0.10%, therefore according to the standard, they are potentially reactive.

5.2 Recommendations

1. 1. It is recommended to extend the research on the proportion of SCMs used in CEM II/B-M, which is very commonly used cement in North Cyprus.
2. It is recommended to extend the research for finding out maximum amount of SCMs which can use in order to reduce the occurrence of AAR.
3. It is recommended to extend the research on other aggregates from other mines from both North and South Cyprus in order to provide extended information on the level of reactivity of aggregates extracted in Cyprus Island.
4. For having more precise experiments, it is recommended to use SEM and XRD test methods before doing mortar bars test methods.
5. It is recommended that, special considerations and precautions must be taken while manufacturing concrete in Cyprus with the most widely used cement type- CEM II/ B-M In order to reduce the risk of AAR.
6. It is recommended to extend the research to generalize the influence of particle size and angularity of reactive aggregates, in order to prevent AAR.

REFRENCES

ACI 201, 2R-08. (2008). Guide to durable concrete. *American Concrete Association, 24,* 1-34.

ACI 22, 1R-98. (1998 (Reapproved 2008)). Report on alkali-aggregate reactivity. *American Concrete Association, 13,* 1-29.

ASTM C 593. (2011). Standard specification for fly ash and other pozzolans for use with lime for soil stabilization. *American Standard Test Methods, 30,* 1-28.

ASTM C 1260. (2000). Standard test method for potential alkali reactivity of aggregates (mortar-bar method). *American Standard Test Methods, 21,* 1-32.

Alexander, K.M., & Davis, C.E.S. (1990). Effect of alkali on the strength of Portland cement paste. *Cement and Concrete, 11,* 146-156.

Berube, M.A., Chouinard, J., Boisvert, D., Frenette, L., & Pigeon, M. (1996). Influence of wetting- drying and freezing- thawing cycles and effectiveness of sealers on ASR. *International Conference on Alkali- Aggregate Reaction in Concrete, 10,* 176-184.

Berube, M.A., Chouinard, J., Boisvert, D., Frenette, L., Pigeon, M., & Rivest, M. (1998). Effectiveness of sealers in counteracting ASR in plain and air entrained laboratory concretes exposed to wetting and drying, freezing and thawing, and salt water. *In Proceedings of the 10th International Conference on Recent Advances in Concrete Technology* (pp. 323-354). Canada: University of Waterloo.

Berube, M.A., & Fournier, B. (2000). Alkali-aggregate reaction in concrete. Netherlands: Gordon & Breach Publisher.

Blaine, R.L., Arni, H.T., Evans, D.H., Defore, M.R., Clifton, J.R., & Methey, R.G. (1971). Compilation of data from laboratory studies. *Building Science Series, 36,* 115-135.

Burrows, R.W. (1998). The visible and invisible cracking of concrete. *American Concrete Institute Monograph, 11,* 78-99.

Bye, G.C. (1999). Portland cement: composition, production and properties. New York, NY: Thomas Telford Publishing, 2nd edition.

Chen, J., Jayapalan, A.R., Kim, J.Y., Kurtis, K.E., & Jacobs, L.J. (2010). Rapid evaluation of alkali–silica reactivity of aggregates using a nonlinear resonance spectroscopy technique. *Cement and Concrete Research, 40,* 914-923.

Cohen, D.R., Rutherford, N.F., Morisseau, E., & Zissimos, A.M. (2012). geochemical patterns in the soils of Cyprus. *Science of the Total Environment, 420,* 250-262.

Cyr, M., Rivard, P., & Labrecque, F. (2009). Reduction of ASR expansion using powders ground from various sources of reactive aggregates. *Cement and Concrete Research, 31,* 436-446.

De Carvalho, M.R.P., Fairbairn, E.D.M.R., Filho, R.D.T., Cordeiro, G.C., & Hasparyk, N.P. (2010). Influence of steel fibers on the development of alkali-aggregate reaction. *Cement and Concrete Research, 40,* 598-604.

Ding-yan, Wu., & Kun-he, Fang. (2004). The research of alkali reactivity of non-siliceous carbonate aggregates. *In Proceedings of the 12th International Conference on Alkali Aggregate Reaction in Concrete* (pp. 453-457). Beijing: University of Beijing.

Feng, X., Thomas, M.D.A., Bremner, T.W., Balcom, B.J., & Folliard, K.J. (2005). Studies on lithium salts to mitigate ASR-induced expansion in new concrete: a critical review. *Cement and Concrete Research, 35,* 1789-1796.

Fournier, B., & Berube, M.A. (2000). Alkali- aggregate reaction in concrete: a review of basic concepts and engineering implication. *Canadian Journal of Civil Engineering, 3,* 12-43.

Gillott, J.E. (1995). Review of expansive alkali- aggregate reaction in concrete. *Journal of Materials in Civil Engineering, 12,* 183-202.

Gouda, G.R. (1996). Microstructure and properties of high-alkali clinker. *In Proceedings of the 8th International Congress on the Chemistry of Cement* (pp. 234-239). Rio de Janeiro: Alba Grafica e Editorab.

Grattan-Bellew, P.E., Mitchell, L.D., Margeson, J., & Min, D. (2010). Is alkali–carbonate reaction just a variant of alkali–silica reaction ACR=ASR?. *Cement and Concrete Research, 40,* 556-562.

Han, S., & Fang, M. (1994). Alkali-aggregate reaction under high temperature, high pressure and high alkali content. *Journal of Nanjing Institute of Chemical Technology, 2,* 1-10.

Haugen, M., Lindgard, J., Akesson, U., & Schouenborg, B. (2002). Experience from using the RILIEM AAR-1 petrographic method among European petrographers-part of the partner project. *Cement and Concrete Research, 32,* 48-64.

Hayman, S., Thomas, M., Beaman, N., & Gilks, P. (2010). Selection of an effective ASR-prevention strategy for use with a highly reactive aggregate for the reconstruction of concrete structures at mactaquac generating station. *Cement and Concrete Research, 40,* 605-620.

Heller, J.L. (2013). Sodium hydroxide poisoning. Retrieved February 27, 2014, from http://www.nlm.nih.gov/medlineplus/ency/article/SodiumHP.pdf

Hobbs, D.W., & Gutteridge, W.A. (1979). Particle size of aggregate and its influence upon the expansion caused by the alkali-silica reaction. *Magazine of Concrete Research, 31,* 235-242.

Idorn, G.M. (1997). In concrete progress: from antiquity to third millennium book. London, UK: Thomas Telford Ltd.

Jensen, V., & Sibbick, T. (2006). RILEM petrographic method: practical use and comparison with other petrographic methods in use. *In Proceedings of the 8th Euro Seminar on Microscopy Applied to Building Materials* (pp. 192-221). Athen: University of Athen.

Katayama, T. (2010). The so-called alkali-carbonate reaction (ACR)-its mineralogical and geochemical details, with special reference to ASR. *Cement and Concrete Research, 40,* 643-675.

Lamond, J.F., & Pielert, J.H. (2006). Significance of test and properties of concrete and concrete-material. *American Standard Test Method International, 8,* 723-754.

Lara, G.W. (2008). Quality evaluation of Portland cement concrete at early age with free resonant column. *Cement and Concrete Research, 38,* 132-176.

Li, Z., Mu, B., & Peng, J. (2000). Alkali-silica reaction of concrete with admixtures. *Journal of Engineering Mechanics, 3,* 210-243.

Lindgard, J., Nixon, P.J., Borchers, I., Schouenborg, B., Wigum, B.J., Haugen, M., & Akesson, U. (2010). The EU "partner" project-European standard tests to prevent alkali reactions in aggregates: final results and recommendations. *Cement and Concrete Research, 40,* 611-635.

Lindgard, J., Çakır, Ö., Fernandes, I., Rønning, T. F., & Thomas, M.D.A. (2012). Alkali-silica reactions (ASR) literature review on parameters influencing laboratory performance testing. *Cement and Concrete Research, 42,* 223-243.

Marzouk, H., & Langdon, S. (2000). The effect of alkali-aggregate reactivity on the mechanical properties of high and normal strength concrete. *Cement and Concrete Research, 33,* 167-185.

Matsuda, F. (2004). Investigation of structures using lightweight aggregate. *Upgrade Symposium on Concrete Repair and Reinforcement, 5,* 13-39.

Multon, S., Cyr, M., Sellier, A., Leklou, N., & Petit, L. (2008). Coupled effects of aggregate size and alkali content on ASR expansion. *Cement and Concrete Research, 38,* 350-359.

Multon, S., Cyr, M., Sellier, A., Leklou, N., & Petit, L. (2010). Effects of aggregate size and alkali content on ASR expansion. *Cement and Concrete Research, 40,* 508-516.

Multon, s., & Toutlemonde, F. (2010). Effect of moisture conditions and transfers on alkali silica reaction damaged structures. *Cement and Concrete Research, 40,* 924-934.

Munn, C.J. (2011). Minimizing the risk of damage to concrete guidance notes and recommended practice. *Cement and Concrete Associate of New Zealand, 8,* 10-80.

Neville, A.M. (1996). Properties of Concrete. New York, NY: John Wiley & Sons.

Nixon, P.J., & Sims, I. (1992). RILEM TC106 alkali aggregate reaction - accelerated tests, *In Proceedings of the 9th International Conference on Alkali-Aggregate Reaction in Concrete* (pp. 70-100). London, UK: Reunion Internationale des Laboratoires et Experts des Materiaux.

Osbaeck, B. (1984). Influence of alkalis on strength development of blended cements. *In Proceedings of the 35th International Conference on the Chemistry and Chemically Related Properties of Cement* (pp.375-383). Norway: University of Oslo.

Owsiak, Z. (2007). Testing alkali-reactivity of selected concrete aggregates. *Journal of Civil Engineering and Management, 18,* 201-207.

Park, S.B., & Lee, B.C. (2004). Studies on expansion properties in mortar containing waste glass and fibers. *Cement and Concrete Research, 34,* 1145-1152.

Ramyar, A., Topal, A., & Andic, O. (2005). Effect of aggregate size and angularity on alkali-silica reaction. *Cement and Concrete research, 37,* 154-183.

RILEM, TC 191-ARP. (2000). AAR-2: detection of potential alkali-reactivity of aggregates-the ultra-accelerated mortar-bar test. *Reunion Internationale des Laboratoires et Experts des Materiaux, 5,* 1-32.

RILEM, TC 191-ARP. (2005). AAR-5: rapid preliminary screening test for carbonate aggregates. *Reunion Internationale des Laboratoires et Experts des Materiaux, 8,* 1-18.

Salihoglu, I., Atalar, J., Resatoglu, R., Ibrahimogullari, M. (2014). KKTC Tas Ocaklari Durumu, Urun Kullanimi, Onemi, Cevresel Etkileri ve Gelevegi.

Shayan, A., & Morris, H. (2001). A comparison of RTA T363 and ASTM C1260 accelerated mortar bar methods for detecting reactive aggregates. *Cement and Concrete Research, 31,* 655-663.

Sims, I., & Nixon, P. (2003). RILEM recommended test method AAR-0: detection of alkali-reactivity potential in concrete-outline guide to the use of RILEM methods in assessments of aggregates for potential alkali-reactivity. *Materials and Structures, 36,* 472-479.

Smaoui, N., Berube, M.A., Fournier, B., Bissonnette, B., & Durand, B. (2005). Effects of alkali addition on the mechanical properties and durability of concrete. *Cement and Concrete Research, 35,* 203-212.

Thomas, M.D.A. (1996). Review of the effect of fly ash and slag on alkali-aggregate reaction in concrete. *Cement and Concrete Research, 15,* 22-53.

Thomas, M.D.A. (1998). The role of calcium in alkali-silica reaction. *Cement and Concrete Research, 18,* 325-331.

Thomas, M.D.A. (2001). The role of calcium hydroxide in alkali recycling in concrete. *Cement and Concrete Research, 23,* 269-280.

Thomas, M.D.A., Fournier, B., Folliard, K., Ideker, J., & Shehata, M. (2006). Test methods for evaluating preventive measures for controlling expansion due to alkali-silica reaction in concrete. *Cement and Concrete Research, 36,* 1842-1856.

Thomas, M.D.A., Fournier, B., Folliard, K., Ideker, J., Shehata, M., & Rogers, M. (2007). Performance limits for evaluating supplementary cementing materials using the accelerated mortar bar test. *American Concrete Institute Materials Journal, 104,* 115-122.

Thomas, M.D.A., Fournier, B., Folliard, K.J., & Resendez, Y.A. (2011). Alkali-silica reactivity field identification handbook. *Pavement Technology, Federal Highway Administration, 2,* 72-108.

Thomas, M.D.A. (2011). The effect of supplementary cementing materials on alkali-silica reaction: a review. *Cement and Concrete Research, 41,* 1224-1231.

Turanli, L., Shomglin, K., Ostertag, C.P., & Monteiro, P.J.M. (2001). Reduction in alkali-silica expansion due to steel microfibers. *Cement and Concrete Research, 31,* 827-835.

U.S. Department of Transportation. (2013). Alkali-aggregate reactivity (AAR) workshops for engineers and practitioners. *Pavement Technology, Federal Highway Administration, 4*, 132-198.

Vivian, H. (1950). Studies in cement aggregate reaction. *Commonwealth Scientific and Industrial Research Organization, 256,* 13-20.

Winter, N.B. (2012). Understanding cement. *Cement and Concrete Research, 42*, 82-123.

Yuksel, C., Ahari, R.S., Ahari, B.A., & Ramyar, K. (2013). Evaluation of three test methods for determining the alkali–silica reactivity of glass aggregate. *Cement and Concrete Composites*, *38*, 57–64.

Zhang, C., Wang, A., Tang, M., Wu, B., & Zhang, N. (2009). Influence of aggregate size and aggregate size grading on ASR expansion. *Cement and Concrete, 39,* 1393-1396.

Zhang, C., Wang, A., Tang, M., Wu, B., & Zhang, N. (1999). Influence of aggregate size and aggregate size grading on ASR expansion. *Cement and Concrete Research, 29,* 109-139.

LIST OF ABBREVIATIONS

AAR:	Alkali aggregate reaction
ASR:	Alkali silica reaction
ACR:	Alkali carbonates reaction
ACI:	American concrete institute
U.S:	United State