ALKALI AGGREGATE REACTIONS IN CONCRETE: A REVIEW OF THE ETHIOPIAN SITUATION

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ABSTRACT

The reaction of aggregates with alkalis in the cement to produce alkali silica reaction and alkali carbonate reaction is reviewed. The effects of the two reactions on the durability of concrete structures are highlighted. By taking samples of aggregates and cement test results, the potential of alkali silica reaction in Ethiopia is preliminarily assessed. Finally a set of conclusions and recommendations are forwarded.

Keywords:
Alkali silica reaction; Alkali carbonate reaction; Cement; Concrete; Durability; Moisture; Sand;

INTRODUCTION

Concrete is one of the most widely used construction materials in the world today. Being used for over 2000 years, it has now become an indispensable part of the day-to-day life of modern society. It is produced by mixing measured amounts of cementing material, fine aggregate, coarse aggregate, water and chemical admixtures to improve its various characteristics such as workability, strength or resistance to chemical attack. The careful selection and proportioning of the different ingredients is vital for achieving the apparent engineering properties of concrete. It is nearly always reinforced with steel embedded within it as it has high compressive strength but poor tensile strength.

Among the reasons making concrete a popular construction material in the world is its versatility. With its high compressive strength which continues to grow up with age, its being water tight, its durability and its high resistance to heat, chemical attack and radiation, concrete is used for the construction of a broad variety of civil engineering structures ranging from the skeletal frameworks of high rise buildings and long spanning bridges to hydraulic structures like dams, spillways and irrigation distribution network. It is also used for the construction of roads, water tanks, silos for chemical storage, bunkers and nuclear reactors.

Despite its long history of use, our understanding of concrete has only really developed in very recent times, particularly with respect to its durability, and as a result of the continuing engineering and scientific developments on the material, practices are constantly changing and it is essential to update oneself with the state-of-the-art methodologies of making it into use to achieve the desired safety and economy.

While it has proved to be a very durable material, concrete is susceptible to failure, most of which arises from the need to reinforce it with steel. The basic role of steel is to take care of tensile stresses developing in the structure, yet because of the expansion in volume of steel resulting from corrosion, it is capable of rupturing the concrete as well. There are also less common breakdowns, which occur in concrete due to chemical inconsistency between the cement paste and some specific types of aggregates. In cold climates, there is the potential for break down by the freeze or thaw action of water near the concrete surface as well. Therefore, more emphasis, which was given so far for the strength characteristics of concrete, should also be equally focused on its durability to avoid premature failures.

Because it is not possible to change the nature of concrete in existing structures easily, protective measures should be taken as deteriorations start to occur to arrest the damage. But before this is attempted, it is essential to have a full understanding of the cause and extent of the breakdown. It may already have reached the point where economical repair is no longer possible. Fortunately, in most cases the onset of these deteriorations does not necessarily guarantee collapse of the structure and repairs can be achieved successfully.

The continued usage of concrete as a construction material is also to a large extent dependent on its relative economy in comparison with other structural materials. Especially in developing countries like Ethiopia, the relative cost of producing concrete where there is a limited manufacture of alternative construction materials like steel is an important factor to be considered in view of the overall economic picture of the countries.

One of the most important factors in the economy of concrete is that about 70% of its volume is occupied by what are known as aggregates. Aggregates are one of the principal constituents of concrete consisting of gravel, sand or rock fragments of different mineral composition. Aggregate particles were originally thought to be inert and unaffected by the concrete paste, and hence they were selected only on the basis of their physical properties such as shape, density (specific gravity), surface texture, and amount and interconnection of internal surfaces. However, it was later discovered that there are chemical reactions that take place between the aggregates and the cement paste and currently, an indepth examination of the microstructure and chemical constituents of the reaction products is revealing the fact that the type of the reactions vary with the mineral composition of the aggregate particles. Following is a detailed description of these deleterious reactions in concrete.

ALKALI-AGGREGATE REACTIONS (AAR)

Alkali-aggregate reactions are chemical reactions in concrete involving certain active mineral constituents often present in some aggregates and the sodium and potassium alkali hydroxides from portland cement paste. The reactions are potentially harmful only when they produce significant expansion and hence cracking of concrete, leading to loss of strength and elastic modulus.

Alkali-aggregate reactions occur in two forms: alkali-silica reaction (ASR) and alkali-carbonate reaction (ACR). Alkali-silica reaction is the reaction between the alkali hydroxide in portland cement and certain siliceous rocks and minerals present in the aggregates, such as opal, chert and chalcedony. The products of this reaction often result in significant expansion and cracking of the concrete and ultimately, failure of the concrete structure. Alkali-carbonate reaction on the other hand is the reaction between the cement hydroxides and certain dolimitic limestone aggregates which can also result in deleterious expansion. Alkali-silica reaction is of more concern than alkali-carbonate reaction because the occurrence of aggregates containing reactive silica minerals is more common. Alkali reactive carbonate aggregates have a specific composition whose occurrence is relatively rare [1,2]. Because of this reason, the phenomenon of alkali-aggregate reaction is these days commonly referred to as alkali-silica reaction.

Because deterioration due to alkali-aggregate reaction is a slow process, the possibility of sudden failure is low. Even in some parts of the world, much concrete made with reactive aggregates still remains in service. However, concrete with alkali-aggregate reaction can cause serviceability problems and aggravate other failure mechanisms such as those that can occur due to frost action, deicing salts, or sulphate exposures.

ALKALI-CARBONATE REACTION (ACR)

The reaction of dolomite in certain carbonate rocks with alkalis from the cement paste has been associated with deleterious expansion of concrete containing such rocks as an aggregate. These rocks have a composition in which the carbonate portion consists of substantial amounts of both dolomite and calcite, and the acid insoluble residue contains a significant amount of clay. Under humid conditions, cracks are formed around the active aggregate particles resulting in a loss of bond between the aggregate and the cement paste. Since the occurrence of dolomitic limestone is very rare in Ethiopia, more emphasis is given to alkali-silica reaction.

ALKALI-SILICA REACTION (ASR)

Alkali-silica reaction is a chemical process which results from the use of certain aggregates in concrete in which particular constituents of the aggregates react with alkali hydroxides dissolved in concrete pore solutions. These alkali hydroxides are derived mostly from sodium and potassium in portland cement and other cementious materials, but occassionally alkalies may be introduced into concrete from external sources or may be relaeased slowly from certain alkali-bearing rock components within the aggregate.

The first written explanation of alkali-silica reaction was published in 1940 by Thomas E. Stanton from his investigation of cracked concrete structures in California [3,4]. Since then, numerous examples of concrete deterioration from other parts of the world have been reported to show that the alkali-silica reaction may become one of the potential causes of distress in structures located in humid environments such as dams, bridge piers and retaining walls.

As the major source of alkalis in concrete is the cement paste, it is essential to evaluate the composition of the cement with respect to this parameter. Normally, raw materials used for the portland cement clinker manufacture are the source of alkalies in cement which typically range from 0.2-1.5% Na_2O equivalent. Therefore, the PH of the pore fluid in normal concretes is generally 12.5 to 13.5, which represents a strongly alkaline fluid in which certain acidic rocks composed of silica and siliceous minerals do not remain stable on long exposure.

Although both Sodium and Potassium compounds are present in Portland cements, alkali content of cements is usually expressed as acid soluble sodium oxide equivalent, which is equivalent to $Na_2O + 0.658K_2O$. The constant 0.658 is the molecular ratio of Na_2O to K_2O (Atomic weights: Na=22.9898, K=39.0983, O=15.9994; $(2(22.9898) + 15.9994) \div (2(39.0983) + 15.9994) = 0.65798$ [5].

Portland cements containing more than 0.6% equivalent Na_2O when used in combination with an alkali reactive aggregate can cause significant expansion due to the alkali-aggregate reaction. Therefore, cements with less than 0.6% equivalent Na_2O are usually designated as low alkali cements and with more than 0.6% equivalent Na_2O as high alkali cements [1,6].

International practice suggests that ordinary concrete with alkali content of 0.6% or less is usually found insufficient to cause damage due to alkali-aggregate reaction irrespective of the type of reactive aggregate [7]. But with concrete mixtures containing very high cement content, even less than 0.6% alkali in cement may prove to be harmful.

The soluble alkali content of the cement produced in Ethiopia in the Mugher Cement Factory, which has been used for several years and is still in use in the country is 0.6% which perhaps indicates that it may not cause severe alkali-aggregate expansion. The Messebo cement which is recently introduced to the construction industry by the newly established Messebo Cement Factory also has an alkali content of 0.6% which is again on the safer side and hence may not be a cause for alkali aggregate reaction by itself. But before any conclusion is made, detailed case studies and laboratory investigations need be made with the variety of locally available aggregates. If for example there is a need of using high amount of cement for spcial purposes in the country, there is a possibility that pronounced deleterious expansion can still occur. Moreover, although it is rare, alkalis may be contributed from the aggregates themselves or from the surrounding environment, in addition to the amount present in the cement and therefore, end remarks can not be stated without further inspection into the case.

MECHANISM OF ALKALI-SILICA REACTION

While many aggregates may react in concrete, damage in structures is observed only when significant amounts of expansive reaction products are formed, they take up water and expand. The reaction products concerned are hydrous gels whose chemical composition always includes silica, alkalies and at least a little calcium. The reaction between the alkalis (sodium and potassium) in concrete and silica reactive aggregates is essentially a two step process. The first step is the chemical reaction between the reactive silica in the aggregate and the alkali present in concrete to produce an alkali-silica gel.

$$\begin{array}{l}\text{Reactive}\\ \text{Silica in}\\ \text{Aggregate}\end{array} + \begin{array}{c}\text{Alkali in}\\ \text{concrete}\end{array} \longrightarrow \begin{array}{c}\text{Alkali-Silica}\\ \text{gel}\end{array}$$

The second phase is the expansion of this alkali-silica gel when it comes in contact with moisture.

$$\begin{array}{c}\text{Alkali-Silica}\\ \text{gel}\end{array} + \text{Moisture} \longrightarrow \begin{array}{c}\text{Expanded}\\ \text{Alkali-Silica gel}\end{array}$$

Depending on the location and on the amount of water available, this gel expands more and more and the increasing expansion and swelling of the gel generates an excessive pressure within the concrete. ASR swelling results from the relative volume increase between the product and reactant phases involved in the reaction. The products expand in pores and microcracks of the cementious matrix. Once this free expansion space is filled, the swelling is restrained and the product phases exert locally a pressure on the surrounding concrete skeleton. It is this pressure that triggers the macroscopic expansion which gradually develops to an extent that is capable of disrupting the entire concrete matrix [8,9].

In conclusion, the following three factors are essential for ASR to occur in concrete.

1. There must be reactive minerals present in the aggregates.
2. There must be sufficient alkali in the concrete to react with the aggregates.
3. There must be sufficient moisture available to enable the chemical reaction.

Alkali-silica reaction and movement mechanisms of the substances responsible for it in the above two reactions are affected by temperature (ASR mechanisms are enhanced by heat, that is, the higher the temperature, the faster they occur) and relative humidity [9]. This effect of temperature on ASR results from the thermoactivation of both processes involved: the dissolution of reactive silica at the aggregate-cement interface and the reaction product formation.

It is an established fact that the relative humidity in concrete is essential for ASR, affecting both kinetics and magnitude. Thus the higher the relative humidity, the faster and more vigorous the reaction would be. Water plays the role of the solvent for the silica dissolution, intervenes as transport media for the diffusion of ions through the pore solution and is a necessary compound for the formation of the various reaction products.

ASR usually takes place at 20°C temperature and 85% relative humidity. The ASR induced cracking results in a decrease in strength and an increase in permeability that increases the susceptibility of the concrete to subsequent damage from processes such as freezing and thawing, corrosion of the reinforcing steel and sulphate attack. The overeall effect is reduced structural integrity and shortened service life of the concrete structure.

In Ethiopian conditions, both the temperature and relative humidity suitable for ASR to take place are prevalent all the year round and throughout the country. Hence, provided other conditions are satisfied, damage due to ASR could be aggravated as a result of the surrounding environmental conditions.

POTENTIALLY REACTIVE SILICA MINERALS AND ROCKS

As presented earlier, siliceous aggregates are potentially reactive with alkalis from portland cement in the presence of adequate moisture in the concrete paste. Silicate minerals are estimated to constitute the largest part of the earth's crust, as high as 80-90%, and the alkali reactive components have been identified in most silicate rocks. Some of the potentially reactive minerals present in these silicate rocks include the following [1,10]:

1. ***Opal (Hydrated Silica Glass)*** – Opal is hydrated silicon dioxide with no appreciable crystalline structure. It contains 5-10% or even greater percentage of water. It is a white or colourless mineral which usually occurs in a variety of volcanic rocks, cherts, and sand stones. It tends to appear in cracks and fractures in rocks. It is actually an ornamental mineral if it appears in massive quantities, but its presence even in small quantities in rocks to be used as aggregates for concrete production could result in a severe damage as it is the most reactive of all silica minerals. The tiny glassy particles present in some sands and rocks in Ethiopia may contain small amount of this mineral and laboratory investigations should be conducted to arrive at a conclusion.

2. ***Chalcedony*** – Chalcedony is another form of silica mineral which is harder and more crystalline than opal. It is a microcrystalline form of quartz. It is basically of hexagonal crystal structure with various colors and white streak. It is less lustrous than opal. If it occurs abundantly, Chalcedony is also a precious stone and it is in fact present in small quantities in almost all types of silica rocks. Observing just the physical properties and common occurrences of Chalcedony, the smooth rounded pebbles usually present in some sands in Ethiopia may contain this reactive mineral.

3. ***Volcanic Glass (Obsidian)*** – Volcanic glass is another amorphous form of silica mineral, usually darker than the above two types mainly due to the presence of iron or magnesium in it. It is also a semi-ornamental mineral if it occurs in large quantities. Aggregates containing this mineral may be reactive depending on its silica composition. Volcanic glass of silica content above 55% is commonly regarded as reactive while that with silica content below 55% is less so. As its name suggests, volcanic glass is formed as a result of volcanic activity. Hence, in Ethiopia, it is necessary to pay particular attention to aggregates quarried from rock deposits of volcanic origin (igneous rocks).

4. ***Tridymite and Cristobalite*** - These are also crystalline forms of silicate minerals that are

usually white or colorless. They are glassy and of tetragonal or hexagonxal crystal structure. They are commonly found in cavities in volcanic rocks. So, like volcanic glass, aggregates of igneous rock origin in Ethiopia should be investigated if they contain substantial amounts of these reactive minerals.

5. ***Quartz*** – Quartz is the most abundant mineral which is found in almost every type of rock. Pertaining to metamorphism, tridymite and cristobalite could gradually convert to a well crystallized quartz that may also be reactive. In Ethiopia therefore, aggregates obtained from rocks that are formed as a result of metamorphism of igneous rocks should be suspected of containig this reactive mineral.

6. ***Silicates*** - Silicates are minerals of either sedimentary or metamorphic rock origin containing clays or micas. They have been observed to be slowly reactive with alkalis and sometimes, their reactivity may not be detected by the ordinary tests. They principally occur in such rock types as graywackes, argillites, phyllites, siltstones, etc. It is strongly recommended that if the aggregate to be used contains significant contents of such rock types, low-alkali cement should be used where available.

In general, aggregates containing most types of silica minerals are believed to be alkali reactive although to different degrees. Some aggregates are potentially reactive while others may not show any sign of reactivity for as long as 20 years. Opal, obsidian, cristobalite, tridymite, chalcedony, chert, andesite, rhyolites, and strained or metamorphic quartz have been found to be alkali reactive in the decreasing order of reactivity.

METHODS OF DETECTING ALKALI-SILICA REACTION POTENTIAL

Several test methods have been used for detection of ASR potential. The following are some of the standard and most common ones ordained by ASTM [11].

1. Mortar-Bar Method (ASTM C 227)
2. Chemical Method (ASTM C 289)
3. Petrographic Examination (ASTM C 295)
4. Accelerated Mortar-Bar Method (ASTM C 1260)
5. Concrete Prism Test (ASTM C 1293)

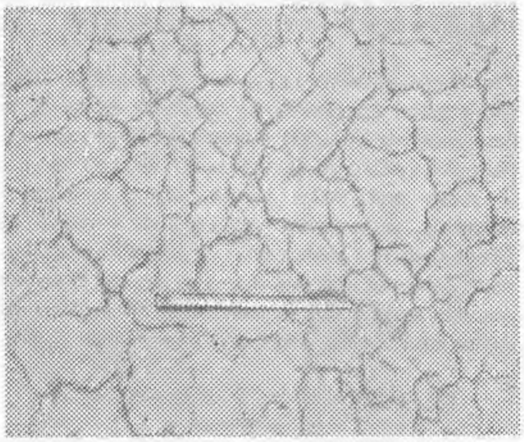
DIAGNOSIS OF ALKALI-SILICA REACTION IN CONCRETE STRUCTURES

Once the necessary conditions for alkali-silica reaction are sustained, the reaction will soon proceed and alkali-silica gel will be formed. Then, in the case of aggregetes of sedimentary rock origin, the expansion proceeds by shedding of the sheet structure and further water absorption whereas in aggregates containing dense particles, reaction rims will be formed around the particles which result in progressive peeling of the peripheral layer continuing inwards. In both cases, the increasing expansion obviously initiates the building up of excessive pressure in the concrete matrix and development of microcracks in both the aggregate and the concrete.

If there is a continued supply of water, the microcracks will extend and enlarge eventually reaching the outer surface of the concrete.

In the case of ordinary concrete which is free to expand equally in all directions, the cracks so formed will be irregular and uniformly distributed over the entire concrete surface, but in the case of a continuously reinforced concrete section or in concrete units that are much longer than their width, the cracks will be parallel to the reinforcement or to the longer dimension respectively. The resulting crack pattern is commonly referred to as map cracking [5,6].

Figure 1 below indicates typical map crack patterns induced by ASR in airfield concrete pavement and road pavement.



(a)

(b)

Figure 1 ASR Induced Cracks (a) High severity map cracks in airfield concrete pavement [12]. (b) Map cracking in pavement [13].

In most of the cases, ASR induced cracks vary in size from 0.1mm for less severe cases, to as much as 10mm in extreme cases. They may be as deep as 50mm but, in most cases, their depth is limited to 25mm. With these dimensions, ASR cracks may be assumed to cause serviceability problems only, but as described earlier, they allow entrance of harmful agents making the structure more susceptible to failure.

Another indication of the increased expansion caused by ASR is closing of expansion joints. Because of the excessive expansion induced by ASR, these expansion joints may be permanenetly closed and in worst cases, the concrete sections may be seen bumping and crushing one other. There is also a possibility that the joints may be misaligned from their original position [6,14].

The third probable indication of potential ASR taking place in concrete structures is emission of the expansive silica gel through the cracks formed on to the surface of the concrete. Initially, the gel is sticky and moist but it will progressively effloresce to a white coating as a result of dehydration and carbonation [6,13]. Occasionally, small pieces of concrete may also pop-out from the concrete surface [2]. In both cases, the exudations can be tested in the laboratory to confirm the cause.

MITIGATION OF ALKALI-SILICA REACTION

Various alkali-silica reaction mitigation techniques are continuously being developed to prevent early age deterioration of concrete structures. In recent constructions, methods of avoiding this harmful reaction should be implemented; however, once this reaction is identified in existing structures, selected treatments should be applied which will help to prolong the useful service life of the concrete structure.

Obviously, to prevent ASR, mineral constituents of the aggregates to be used in the concrete should be investigated and their potential alkali reactivity should be tested. If they are found to be deleteriously reactive, they should not be used in the concrete. But if there is no any other alternative, the alkali contribution from the cement and all other possible sources like some admixtures and the aggregates themselves, should be substantially reduced (to less than 0.6% Na_2O equivalent, and to less than 0.4% Na_2O equivalent for potentially reactive aggregates [15]) to prevent alkali attack. In other words, low alkali cement should be used with such reactive aggregates or cement replacement materials should be used to replace some part (25-40%) of the high alkali cement.

ALKALI-SILICA REACTION IN ETHIOPIA

As has been mentioned in the previous discussions, alkali-silica reaction can occur in concrete structures if the three preconditions are satisfied at the same time, i.e. if reactive constituents, alkalis and moisture are all present. In the absence of one of these preconditions, deleterious ASR will not take place and hence the structure will not be subjected to ASR induced failure. Therefore, before concluding whether there is a potential for ASR in Ethiopia or not, the above three preconditions should be assessed carefully and deeply. Following is a preliminary assessment of the potential occurence of each precondition in Ethiopia.

OCCURRENCE AND COMPOSITION OF SOME LOCALLY AVAILABLE AGGREGATES

As can be seen from the simplified geological map of Ethiopia shown in Figure 2, majority of the country's rocks are predominantly of volcanic origin extending from the north eastern and north western parts of the country to the central, south central and south western parts. This includes the western, south western and eastern parts of Tigray region, Afar, majority of the Amhara region covering Gojam, Gondar and parts of Wollo, central Ethiopia including Addis Ababa, western and south western parts of Oromia and northern part of SNNP. The most common of such volcanic rocks are basalt, ignimbrite and tuffs. The later two are primarily found in areas near the Rift Valley.

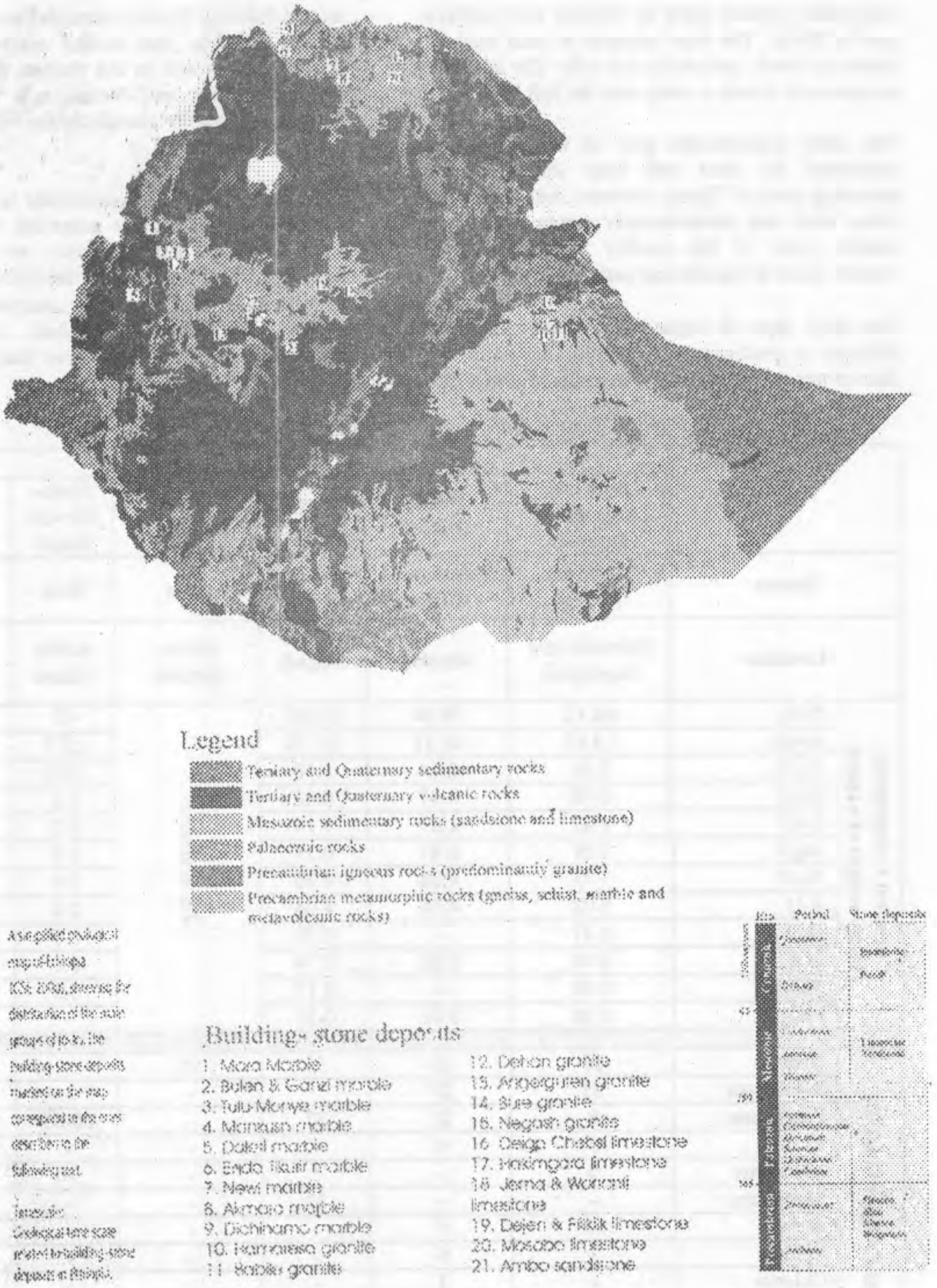
The other considerable part of the country is dominated by sand and lime stone deposits including parts of Tigray, southern Amhara around Abay basin and predominantly eastern and south eastern parts of the country covering Harrar, western parts of Ogaden and eastern SNNP.

The third type of major rock deposit found in Ethiopia is predominantly granite located at the four corners of the country, i.e. in the southern part around Sidamo, in the eastern part around Harrar, in the northern part around central and north western Tigray and in the western part mainly in Wellega, Gojam and Benishangul Gumuz. This rock deposit mainly constitutes the minerals quartz, feldspar and mica.

From these major rock ocurences in the country, the ones which could be suspected of undergoing expansive alkali-silica reaction are the granite representative samples from the different localities to determine their potential reactivity. Table 1 shows sample data of which chemical and mineralogical composition have been carried out [17,18,19].

Table 1: Chemical and mineralogical composition of selected rocks.

		Samples					
		Bure and Angerguten Granites	Dehan Granite	Negash Granite	Ambo Sandstone	Akaki-Olivine Basalt	Feldspar Basalt
Source		Gojam and Wellega	Benishangul Gumuz	West Tigray	Shoa	Shoa	Shoa
Location		Bekotabo and Angerguten	Metekel	Negash	Ambo-Senkele	Addis Ababa	Addis Ababa
Chemical Composition (% by weight of oxides)	SiO_2	68.12	70.94	70.08	Not available	47	61.62
	Al_2O_3	14.85	14.15	15.78		15.7	15.1-15.2
	Fe_2O_3	3.51	2.14	1.18		14.8	8.42
	MnO	0.05	0.07	0.02		0.2	0.2-0.3
	CaO	1.42	1.87	1.14		8.0	3.2-3.6
	MgO	1.01	0.41	0.31		5.6	1.4-1.7
	Na_2O	3.75	4.28	4.70		3.4	4.9
	K_2O	5.02	4.58	3.64		0.9	2.6-2.7
	H_2O	0.47	-	0.50		0.7	-
	LOI	0.44	0.92	0.74		1.1	0.5-0.9
	TiO_2	0.68	-	0.17		3.3	1.2-1.3
	P_2O_5	0.38	0.01	0.21		-	-
Mineralogical Composition (%)	Quartz	25	30	35	95	-	-
	K-Feldspar	55	27	-	-	-	-
	Plagioclase	9	20	27	-	60-65	70-80
	Biotite	5	4	-	-	-	-
	Muscovite	5	-	5	-	-	-
	Microcline	-	-	33	-	-	-
	Sericite	-	6	-	-	-	-
	Epidote	-	6	-	-	-	-
	Chlorite	-	3	-	-	-	-
	Clinopyroxene	-	-	-	-	10-20	-
	Pyroxene	-	-	-	-	-	10
	Olivine	-	-	-	-	10-20	Trace
	Hematite	-	-	-	-	5-10	-
	Glass	-	-	-	-	-	Up to 25
	Others	1	4	-	5	-	-



A simplified geological map of Ethiopia (GSE 2000), showing the distribution of the main groups of rocks. The building-stone deposits marked on the map correspond to the ones described in the following text.

Inset right: Geological time scale related to building-stone deposits in Ethiopia.

Figure 2 Geological Map of Ethiopia, GSE 2000 [16].

Refering to Table 1, the first three granites have almost the same amount of SiO_2 content, about 70% which is high of course, but only 25-35% is in the form of quartz which itself is least reactive of all the silica minerals. On the other hand, they contain appreciable quantities of the alkali oxides which may gradually contribute to the total soluble alkali content in the concrete besides the cement. Hence, although potential reactivity might not be expected of these rocks because of their limited content of quartz, the high silica content and the presence of the two strong alkali hydroxides obviously initiate further investigation.

In the case of the sand stone deposit at Ambo, it is predominantly composed of the mineral quartz which under high alkali exposures is reactive to an appreciable degree. Therefore, one of the quick and less expensive tests could possibly be conducted on it to assess its degree of reactivity.

The alkali-olivine-basalt, being a fine grained extrusive rock, its glass content is generally low. Hence, it is not deleteriously reactive with the alkalis in hydraulic cement paste. However, the relatively higher concentrations of SiO_2, alkalis and glass in the feldspar basalt are apparently clear and therefore its alkali reactivity should be assessed in a more detail.

The other assessment could possibly be that of the locally available sand which is used as a fine aggregate in constructions. Table 2 gives the oxides concentration of silica sand obtained from three localities [17].

Table 2: Oxide concentration of silica sand obtained from different localities

		Sample		
		Silica Sand		
Source		Shoa	Tigray	Tigray
Location		Mugher	Adigrat	Sinkata
Chemical Composition (% by weight of oxides)	SiO_2	96.1	99.5	98.4-99.6
	Al_2O_3	1.91	0.27	0.1-0.6
	Fe_2O_3	0.32	0.04	0.1-0.33
	MnO	-	<0.1	-
	CaO	0.1	<0.1	-
	MgO	0.1	<0.1	-
	Na_2O	0.1	<0.1	-
	K_2O	0.1	<0.1	-
	H_2O	-	0.13	-
	LOI	0.49	0.24	-
	TiO_2	-	<0.02	-
	P_2O_5	-	-	-

In this case, although alkali contribution from the sand is minimal, the concentration of SiO_2 is so high that substantial ASR can take place if the other favourable conditions are satisfied. The major sand supply to Addis Ababa is derived from the Awash basin which is located about 120km south east of the city and a similar investigation is required to assess the potential of reactivity.

ALKALI CONTENT OF CEMENTS PRODUCED IN ETHIOPIA

For so many years, the Mugher Cement Factory in Addis Ababa was the major producer and supplier of cement in Ethiopia. But, because of the proliferation of concrete constructions in the country in recent times, this factory alone was unable to meet the entire cement demand in the country and therefore, Messebo Cement Factory is recently established in Tigray region where there is abundant supply of the raw material.

The soluble alkali content of the cement produced in the Mugher Cement Factory is 0.6% which is right at the margin of low and high alkali cements. According to the very recent (20.10.04) test result of the quality control laboratory of Messebo Cement Factory, the Na_2O and K_2O concentrations of the OPC produced are 0.35% and 0.38% respectively which again yield Na_2O equivalent of 0.6% [i.e. $0.35+0.658*0.38=0.600$ / Na_2O eq = $\%Na_2O + 0.658\%K_2O$].

According to the foregoing discussion, for potentially reactive aggregates, the total soluble alkali content in the concrete should be sufficiently below 0.4% to avoid deleterious ASR. From the above observation however, there is no clue as to say that such potentially reactive aggregates occur in Ethiopia. And therefore, the soluble alkali content of both cements is in the acceptable range in our conditions.

Practical experience in some European countries suggests that deleterious ASR will not take place as far as the total alkali contribution from all sources is kept below $3kg/m^3$ [6]. This means in our case, assuming that all the alkalis are supplied only from the cement paste, as high as $500kg/m^3$ cement is required to reach this limiting value using our locally produced cements. Comparing this value with the quantity of cement used in everyday construction reveals that there is a good safety margin which may account for contribution of alkalis from other sources like from the aggregates themselves, from some chemical admixtures or from surrounding alkaline environments. However, keeping this in mind, more investigation is quite necessary to arrive at tangible conclusions.

NATURAL CONDITIONS OF MOISTURE AND TEMPERATURE

The surface layer of a concrete section is the only driest portion which does not react much and hence does not expand appreciably. The inside part of any concrete section however is seldom dry and hence subjected to ASR. Moreover, as a result of permeability of ordinary concrete, water enters to the inside easily and keeps the relative humidity in the concrete high enough for ASR to take place.

In addition to the high relative humidity (>50%) in the air present in many places in Ethiopia, highlands of the country (the temperate zone) receive a high amount of rainfall ranging from 1300 to 1800mm annually, with a corresponding average temperature of about 16°c. Even the subtropical zone which covers most of the highland plateau of the country receives an annual rainfall of 500 to 1500mm with an average temperature of 22°c [20]. Hence, as far as ASR is not precluded, there is a potential replenishment of moisture to the concrete in Ethiopian conditions.

Moreover, in recent studies, it is found out that nearly all concrete will have an internal relative humidity of more than 80% provided that one of its sides is on the ground and the relative humidity is measured at a depth of 2 in. (5.08cm) from the exposed surface-even in the desert [14]. This means, important structures like concrete bridges, pavements, dams and foundations are always liable to contain high moisture inside them irrespective of their location. Therefore, abundance of moisture for ASR to take place is not questionable and hence it is imperative to limit its amount as far as practicable to avoid deleterious expansion.

CONCLUSIONS AND RECOMMENDATIONS

1. From the above discussion, the apparent reason for not expecting potential alkali-silica reactivity in Ethiopia is the low alkali content of the cements produced and distributed all over the country. As stated previously, the Na_2O equivalent of both the Mugher and Messebo cements is 0.6% which can cause deleterious ASR only with potentially reactive aggregates. From the data obtained above, there is no indication of the occurrence of such potentially reactive aggregates in the country. However, only this assessment is not deemed to be sufficient to make a final conclusion and therefore, detailed laboratory analysis of a number of representative aggregate samples from all over the country should be conducted with particular focus towards susceptibility of the aggregates to ASR.

2. Although the potential contributor of alkalis in concrete is the cement paste, there is also a possibility that alkalis may be supplied from other sources like the surrounding environment, some chemical admixtures and the aggregates themselves. Again from the foregoing assessment, the two strong alkali oxides, namely Na_2O and K_2O, are present in some of the rocks available in the country to as high as 9% combined. As aggregates constitute 70-80% of the total volume of concrete, the cumulative contribution of alkalis from these aggregates shouldn't also be regarded as insignificant and hence it initiates further investigation too.

3. Quantitative assessment of possible alkali contributions from other sources like the ground water and other marine environments in the country should also be conducted before decisions are arrived at hastily. Detailed analysis and specification for, chemical admixtures to be used in the construction industry is also helpful to limit their soluble alkali content.

4. Apart from these, as water is essential for ASR to take place, gross moisture entry to concrete structures should also be prevented as much as possible in case there is unseen potential for alkali-silica reactivity, and hence the following measures will be helpful to address this aspect.

    a) Proper drainage of concrete structures to avoid water retention on them.
    b) Avoiding the use of high water-cement ratio for merely enhancing workability which makes the concrete more permeable and hence more susceptible to gross moisture entry.
    c) Taking adequate precautions while placing and compacting concrete and strictly practicing proper curing right after placement.
    d) Introducing the use of cement replacement materials like GGBS to obtain more compact and hence less permeable concrete.

It is the responsibility of all concerned professionals working in the country to prove that there is in fact no problem of ASR in the country. Detailed laboratory and field investigations as well as selected case studies should be carried out in areas suspected of this reaction. In case any deleterious ASR is discovered, it should be duly addressed before it gets out of perspective.

6. Modern construction techniques like the use of cement replacement materials (for instance, GGBS and PFA) should be increasingly exercised in the country as they have multidirectional advantages with respect to reducing ASR. The use of other beneficial concrete admixtures should also be widely promoted which parallely improve the overall quality of construction in the country.
7. The current Ethiopian practice in aggregate production and usage is nonsystematic and lacks consistency creating problems both for producers and consumers. This calls for standardization of aggregates interms of their chemical composition, specific gravity, sizes and other relevant parameters. Attempt should thus be made by the concerned relevant authority to standardize aggregates, both fine and course, so that the required quality could be achieved consistently and at a reasonable cost.
8. Finally, further detail study on the subject of alkali-silica reaction by taking more representative samples is recommended.

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