INTERNATIONAL JOUNAL OF: ENGINEERING RESEARCH AND TECHNOLOGY

TIMBOU-AFRICA ACADEMIC PUBLICATIONS
INTERNATIONAL JOURNAL, NOVEMBER, 2022 EDITIONS
VOL. 11 NO. 5 ISSN: 2707-5654

A REVIEW PAPER ON ALKALI SILICA REACTIONS IN CONCRETE

***SALISU ABDULLAHI DALHAT; **ABUBAKAR MAGAJI; & **IBRAHIM A. SUKAMARI**

*Civil Engineering Technology Department, Federal Polytechnic Bauchi, Bauchi State, Nigeria. **Civil Engineering Technology Department, Federal Polytechnic Mubi, Adamawa State, Nigeria

ABSTRACT

Alkali–Silica Reactions (ASR) occurs over a long period of time. Reactions take place in concrete when the hydration product known to be highly alkaline cement paste and reactive non-crystalline silica which is found in many common aggregates, in the presence of moisture reacts. This results in the deterioration of concrete structures and can prove to be

Introduction

The sign of ASR is the occurrence of significantly large amounts of hydrous calcium aluminate sulphate $[Ca_6AL_2(SO_4)_3(OH)_{12} \bullet 26H_2O]$ mineral (ettringite) in concrete. A typically colourless to pale yellow mineral crystallizing in the trigonal system, the prismatic crystals are typically colourless turning white on partial dehydration (see figure 1). The Calcium Hydroxide in the pore water is responsible for freeing the hydroxyl ions generated and also intensifies ASR. Signs of the alkali–aggregate reaction are observable in concrete after a period of about 15 to 30 years.

effective over time. The problem with this process is that it may not be noticeable during early stages with naked eyes but in the event of occurrence, it leads to considerable to severe damage of concrete structures. In areas with significant moisture during construction, Alkali Silica reactions are likely to be a problem in the long run.

Keywords: Alkali-Silica Reaction, Crystalline, Hydration, Moisture

To investigate early stages occurrence of ASR development, use of microscopy technique is required.

This research aims at simplifying the process of investigating the occurrence of alkali-silica reactions from concrete samples and developing a standard and simple procedure which does not require complicated machinery and lab conditions to carry out the work. It bridges the gap on economical aspect of laboratory work and on-site activities. Ordinarily, ASR is seen either by sulphate identifying means or by microscopy. Simple volumetric calculations and failure monitoring have not been employed. This is because normally it will take years to detect the occurrence of ASR.

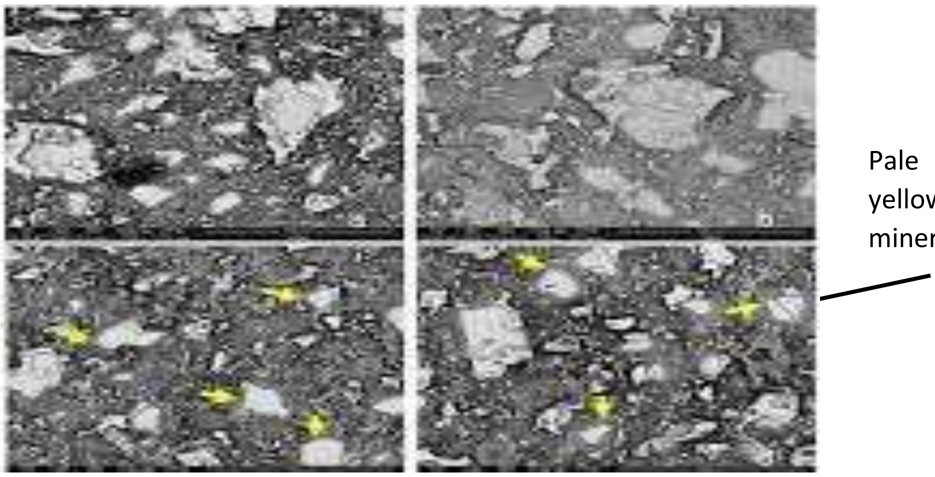

Figure 1: ASR Products with high alkali content (https://www.understanding-cement.com/alkali-silica.html)

FUNDAMENTALS OF THE OCCURRENCE OF ASR

Conventional Portland cement was measured and seen to have contributed around eight per cent of the whole anthropogenic CO_2 emission globally. Alkali Stimulated materials are looked upon as the probable material to be used as a replacement to Portland cement which can reduce the emission of CO_2. Alkali activated, material is what contribute to the occurrence of ASR (Luukkonen et al. 2018).

According to Richardson et al (2016), the products of hydration of the main silicate phases (Alite and Belite) in Portland cement are the same. These are calcium hydroxide and calcium silicate hydrate. A linear relationship was developed between Silica, Aluminium, and Calcium ratios in concrete mixes with cement blends that contain Alumino silicates as follows:

$$\frac{Si}{Ca} = 0.428 + 2.366\left(\frac{Al}{Ca}\right) r^2 = 0.98 \qquad (1)$$

Non crystalline silica is common in many aggregates and the reaction of that amorphous Silica and Alkaline cement paste causes the formation of Alkali Silica Reactions. The reactions occur in the presence of moisture. Some of the cement replacement materials have relatively high quantities of reactive silica. Rice husk ashes which are residues found from processes done in productions and as a result of agricultural wastes combustion also can have a high amounts of silica which is reactive content and by percentage weight (greater than or equal to 90 by percentage weight). Amorphous silica is also said to originate in geothermal silica in the processes of geothermal power plants according to (Luukkonen et al. 2018).

It is imperative to determine the likelihood of the occurrence of alkali silica reactions during the early stages or during the construction stages of reinforced concrete structures. Zewdu et al (2013) states that the low service life of mended concrete structures has of late becomes of high concern.. The following diagrams give a summary of their findings on the repair of structures.

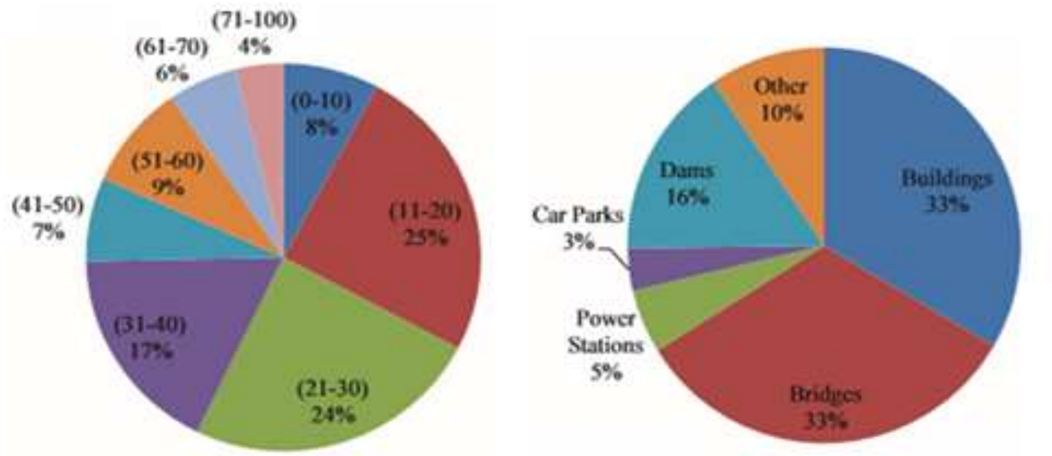

Figure 2: Distribution of the structure by type (https://www.understanding-cement.com/alkali-silica.html)

Structural failures that were as a result of Alkali activated reactions were stated as having caused 4% of the total damage of concrete structures in the whole of Europe, Zewdu et al (2013).

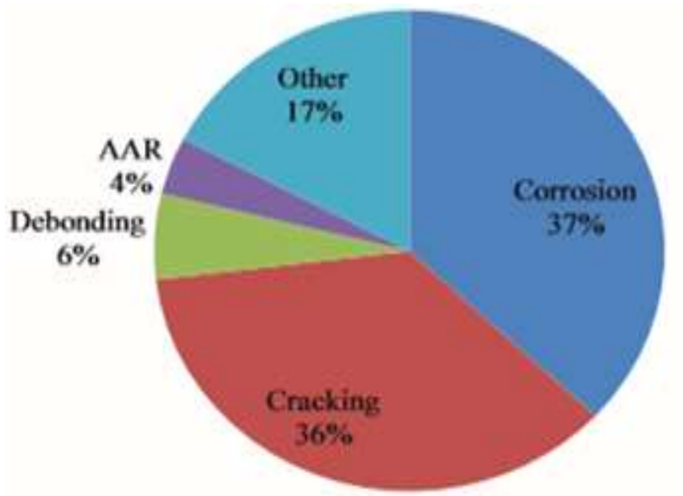

Figure 3: Failure mode of the concrete repairs (https://www.understanding-cement.com/alkali-silica.html)

Some Forms of active silica minerals are shown in the figure 4.

Figure 4: a, b, c forms of reactive silica (www.johnbetts-fineminerals.com)

Maddalena and Hamilton (2017) carried out an investigation in which they used injection of silica in concrete by use of Nano-silica material and after that did a comparison with diverse injection models. The figure beneath this paragraph shows their model of silica penetration depth after injection.

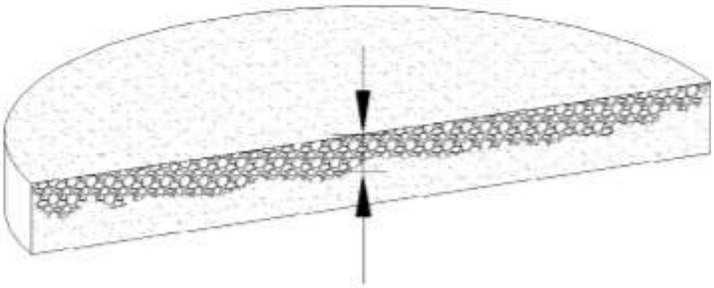

Figure 5: Model of Silica Penetration Depth (www.johnbetts-fineminerals.com)

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ISSN: 2707-5654

Mechanism of ASR

The reactions between the amorphous or reactive silica and the active alkalis which forms the alkali-silicate gel occur initially at the aggregate/cement paste boundary

$$Ca(OH)_2 + H_4SiO_4 \longrightarrow Ca^{2+} + H_2SiO_4^{2-} + 2H_2O \longrightarrow CaH_2SiO_4 .2H_2O \qquad (2)$$

The founding principle to this research is Alkali silica reactions modelling. The model helps to develop volumetric analysis of reactions within a theoretical and hypothetical concrete sample. Conditions needed for ASR are shown below. Cubic cell of concrete of side s containing only one reactive particle of initial diameter D are used in this model reactions.

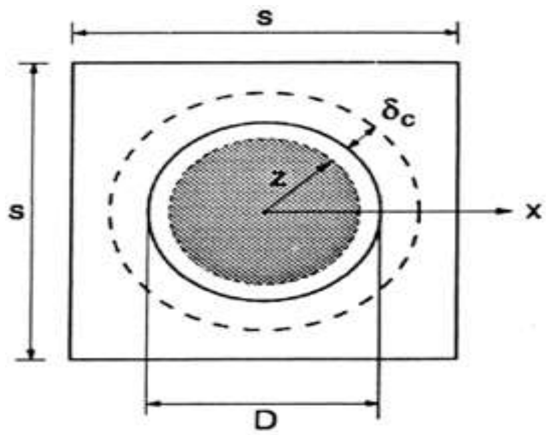

Figure 6: ASR Model (www.johnbetts-fineminerals.com)

For ASR to occur, the active silica and active alkalis must react with water. Reactive silica and the alkalis are needed to result in the formation of the alkali-silicate gel which occurs first at the aggregate and cement paste boundary. It was recommended that High Performance Concrete (HPC) is susceptible to ASR if especially when reactive aggregates are used, and that the reaction becomes complex depending on the admixture(s) used (Ferraris, 1995). They have known the gel to contain Sodium, Potassium and Calcium silicate. There are other factors that can be considered to be causing the Alkali aggregate reactions in concrete.

According to some reports, very small portion of the reactive material in the aggregate may be necessary to cause the distraction of the concrete (as low as about 0.5%). The gel is soft, but it takes in a large amount of water (by a process called osmosis). Due to this phenomenon, the gel attracts water and swells with the hydraulic pressure developed leading to an overall expansion of the concrete by exertion of stresses within. One reactive unit of initial diameter D and this means obviously $\rho_s E_s s^3 = \pi D^3/6$ Where E_S = silica concentration = mass of reactive silica per unit volume of concrete (kg/m³), ρ_S = density of silica.

$$S^3 = \frac{\pi D^3 \rho_S}{6E_S} \quad (3)$$

Overview of previously accomplished ASR work

According to Ronning et al (2013), the development of tests to determine the standard test of ASR has proved to be difficult. The reason they state is the difference in Alkali levels from place to [place. There is there for a need to perform petrography tests to determine other significant parameters. Performance test to determine the following have been employed.

Standard concrete test for aggregates combinations (fixed alkali level). Concrete test need to be conducted so as to detect the required reasonable alkali threshold level, i.e. at which the level of alkali is critical to a particular and very specific aggregate. Required Concrete test which are important for determining aggregate combinations incorporating various fractions at acceptable pessimism effect as given earlier Required Concrete test which are essential for developing cement or binder combination, with which specific Alkali Silica Reaction susceptible aggregate combination, and also grading will not at the end cause damages. Required Concrete test which is useful for developing a regional cement or binder combination to help mitigate structural damages when they combined with different aggregates for example a

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ISSN: 2707-5654

particular regional would be "worst case reference aggregate. "Concrete Required test for combination of the constituents intended for a precise job mix (but at a fixed, expectedly worst case w/b ratio).
The detection of alkali minimum levels for a particular area or country is doable. This exercise has indeed been done across Nigeria and in other areas as well. Due to the various minerals which are generally contained in aggregates, the severe disruption extent of the cement paste in concrete may come out different from place to place. This is dependent on several factors of cause. The idea of coming up with a standard test on this matter then until now has a number of challenges to face but still, focus can be put on developing the proposed standard. The test for aggregate which aims to obtain the possible combinations deemed reasonable and possible is also a way of determining pessimism intensities in the exercise. All these attributes of concrete material need to be established so that a standard experimental test is put forward to solve the problem. The steps to take will further be illustrated by the picture diagram figure 7.

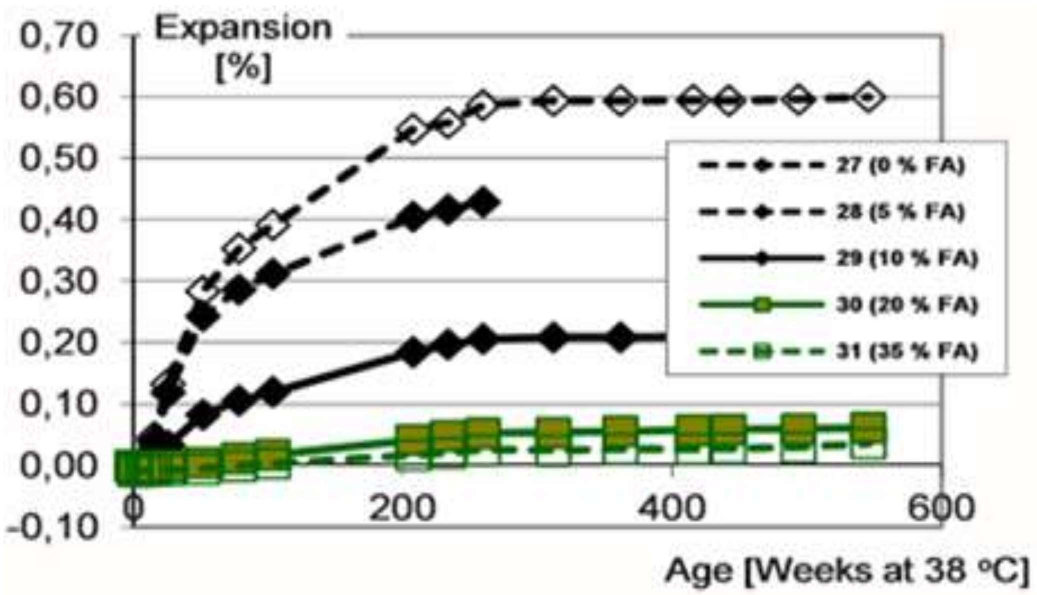

Figure 7: Concrete prism expansion with increasing fly ash replacement (www.johnbetts-fineminerals.com)

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Performance tests refer to the process of obtaining the constituent materials for the concrete prism testing exercise. This has been adopted in countries like Norway. A very detailed and differentiated system of specification, which is based on numerous researches, was considered by the American Association of State Highways Transportation Officials (AASTHO) and accepted into their systems. Apart from Petrography, There was also the accelerated mortar bar testing .All of these target researches were done across Europe, mainly. Based on RILEM (International union of laboratories and experts in construction materials, systems and structures).What still remains difficult is to establish globally accepted expressions that can be used to calculate the rate, occurrence or predict the occurrence of Alkali silica reactions to help curb this problem which affects concrete structures and also affects the economy.

EXPERIMENTAL WORK

The guiding equation in the experimental work is given below:

$$Ca(OH)_2 + H_4SiO_4 \longrightarrow Ca^{2+} + H_2SiO_4^{2-} + 2H_2O \longrightarrow CaH_2SiO_4 .2H_2O \qquad (4)$$

The materials for the experiment includes; reactive pure silica, widely accessible alkaline material, 10 Graduated Cubes, Water and warm bath and Thermometer.

Background to ASR modelling experiment proposal

A theoretical relationship showing Alkali Silica reaction model equation (iii) is simulated by use of samples. Using the exact pure silica and known amount of alkalis made to react in solution to model 100% reactive samples of aggregate containing all silica and also 100 % of all alkaline cement paste. The sample is put in small quantities and small cubes are used as containers to measure the expansion or increase in volume due

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ISSN: 2707-5654

to formation of compounds modelling calcium- silicate hydrate. The idea of this approach is to allow determination of likelihood of problematic ASR on a concrete mix on site. The approach is meant to simplify the process of determining ASR reactions at a very early stage of the development of ASR.

There is need to study carry out several of such tests in determining a general standard of the minimum amount of time that needs to at least be spent carrying out this experiment. Theoretically, it is known that ASR can be visible after about 15 years. It is also known that ASR cannot be visibly determined during early stages and hence there is need to develop a way to avoid damage to properties at later stages. The aim of this proposed experimental procedure is to solve the problem of having to use microscopy technique always to determine ASR. The steps laid out in the following sections are general steps but can be custom adjusted to suit particular site and particular circumstances.

Procedure

The procedures for this research are explained in details in this section. Firstly, measure the mass of the graduated 10cm x 10cm x 10 cm cube and record W_1, make ready to mix equal volumes of Alkali and Silica, (V_S and V_A) is 150 cm^3 and Record the volumes, then add equal amounts of silica and alkaline paste in solution into graduated cube, and measure the weight, $W_2 = W_S + W_A$ i.e. weight of Silica +weight of alkalis. After that then, start off timer watch. Measure the temperature of the contents in the cubes and after every 20 minute intervals, measure and record W, V_{Total} and temperaturet. Hence, determine about10 values of ASR (simulated) using the 10 cubes. And with coordinates of weight and or volume change, plot graphs of (W_2-W_1) against t.

On top of the contents in the graduated container cubes, add a known quantity of the mixed concrete to the cubes, in another graduated container, add mixed concrete from site to the same weight V, and allow to react.Record the initial volumes Aand weights after adding concrete, measure and record final volume and the differences, plot graphs of the volumes with concrete added against time. Determine the graphs. After the graphs have been determined, a comparison of the two graphs can be done and the graphical values of Reinforced concrete volumes with time can be determined. Since ASR causes cracks in concrete through swelling, the volume change in the samples is representing the ASR swelling.

Interpolation

To determine the ASR values for any concrete sample, the concrete mix is tested and until there is considerable change on the volumes relative to the pure ASR mixes. The disadvantages of proposed method of ASR prediction include, obtaining the materials can be costly, Procedure needs to determine the volumes and then eventually not use them. While, the advantages of proposed method of ASR prediction, Easy to follow and can be done on site. It is also not causing delays.

RESULTS AND DISCUSSIONS

The graphs of Volume against time of concrete added to 100% reactive sample is used to determine the rate of change of volume.

$$\frac{dV}{dt} = x_i \qquad (5)$$

Where x_i to x_n will be values determined by drawing tangents to graph.

Since there are many trial cubes for a start (10), the constant of equation (v) can be determined. This relationship is used to predict the rupture of concrete with time, as the plasticity of concrete is known. Further developments can be done and studied further. The more deviated the results are from those of pure Alkali and Silica, the better the concrete mix. The procedure can be used to determine relationship between ASR reactions and also to establish localized relationships between aggregates from different places. The results will need a practical approach to determine the minimum number of hours that must be spent to start seeing changes when the concrete is added to the 100% reactive silica and reactive alkaline substance. In some cases the occurrence of Delayed Ettringite formation happens simultaneously with ASR, so one needs to know how to differentiate the two. Proposed minimum time would be to start with over 48 to 72 hours and then adjust if this proves to be too much. If the formation of ASR reaction products happens earlier it may be wiser to do more trials and in shorter periods of time to ensure minimum time. If there is no considerable change on the materials set up, it means there is need for more time in carrying out the experiment.

Temperature also needs to be monitored. The idea is to maintain the same standards and records well kept. Temperature can be used be contributing factor to the time taken for the concrete ASR to start and be seen, and one reactive particle of initial diameter D, obviously.

$$S^3 = \frac{\pi D^3 \rho_S}{6E_S} \qquad \text{From equation (3)}$$

Where E_S = silica concentration = mass of reactive silica per unit volume of concrete (kg/m^3), ρ_S = density of silica. While, the size of the cubes was maintained at 1000 cm^3 to ensure uniformity, and also to allow a relationship to be developed from the results. The same exercise will involve a look on the change in mass and change in volume. The same experiment allows a comparison to be done on the two. A relation that will be governed by the 1000 cm^3 cubes maximum volume will be carried out. Two sets of graphs showing the relationship will be established from then practical and these will be compared to the graphs and findings of the pure reactive agents, silica and alkali. From the formula already given for the concentration of silica, $\rho_S E_S s^3 = \pi D^3/6$, volumetric calculations

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ISSN: 2707-5654

can be done also and a numerical relationship developed between the parameters.

Since all the finding are in reference to that formula given above, the equation can be used to then further develop a numerical expression and substituting into the equation means the missing parameters can be easily calculated. It may help to know what caused a concrete structure in particular to develop in deterioration until it totally fails.

CONCLUSIONS

ASR results from the reaction of alkalis and reactive silica. The alkali Silica reactions investigations have not been fully studied. A few comprehensive researches have been done on the subject. However, in Europe, Alkali Silica Reactions seem to have caused the minimal damage of about 4% according to 2016 report but the extent of damage is usually severe. In addition, since the damages are visible after a long period, it may be difficult to reinstate a reinforced concrete structure, which has considerably gone through a significant span of its intended life span. Alkali Silica Reactions are difficult to monitor as compared to other easily visible deteriorations of concrete structures. It may be helpful to the concrete research fraternity to invest more in developing early stage recognition of such problems more than the repair of the structures which is more of a reactive way to solving the problem when there are more active ways of curbing the occurrences.

The development of performance analysis actions is in development but resolution is expected to be restricted to “combinations of constituent’s concept” and for example not including enquiry into the effect of fluctuating the values of w/c-ratio. More or less of the nations that have already adopted this performance tests for the drive of finding combined aggregate and cement and/or binder performance.

The addition of fly ash to the cement mill as a cement replacement material enables co-processing greatly in a way that seems to improve

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ISSN: 2707-5654

the alleviating effect, successfully increasing quality assurance together with overall performance. Alkali Silica Reactions can occur simultaneously with Delayed Ettringite formation and both processes can be detrimental to structures, it is therefore necessary to study the extent of damage of each process given that one may not identify the proximate cause of the structural damage.

RECOMMENDATIONS FOR FURTHER STUDY

It is imperative to further study the behaviour of Alkali Silica Reaction with a need to investigate if there are ways to accelerate the occurrence in concrete without changing the properties of the concrete that are required to fulfil the structural use of these reinforced concrete structures. There is need to investigate the possibility of Alkali Silica Reaction effects on all concrete materials and possible Alkali Silica Reactions alterations when cement replacement materials are totally used.

There is also need to investigate if it possible to add chemicals which will reverse the build-up of water which swells up inside the concrete mass and then exerts stresses on the concrete and thereby leading to crack formation. Another area of study is to investigate the possibility of incorporating drains, which will immediately provide passage of water out of the concrete mass, and thereby avoiding the swelling up of the concrete mass. This is because studies in the past done on the subject show that the cracks in the concrete mass are as a result of the internal stress build up that is as a result of volumetric changes as the water that bulges in the concrete forcibly tries to occupy space inside then concrete. Another area of study is the cost implications of the Alkali Silica Reactions. An understanding of the damage broken down to cost per cubic meter of concrete can be used to fully understand the cost implications of the structure.

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An investigation, which can also be very important, is the formation of comparative expressions of different areas to determine the constants that will allow standard expressions of the calculations of these alkali silica reactions regardless of varying material constituencies. These expressions will make use of constants and allow the incorporation of research findings that have already been done and accepted by AASHTO. This will help to deal with the problem of varying compositions of alkali levels from one place to the next. There is need to investigate self-healing with mineral additives, self-healing by means of bacteria on these Alkali Silica Reactions. The concept of simultaneous DEF and ASR is not well understood. In some cases, the occurrence of Delayed Ettringite formation happens simultaneously with ASR, there is need to understand the relationship between

Recommendations for study on the rehabilitation of Alkali Silica damages may include; Demolition and building again, to use waterproof, to do nothing else but wait for swelling to grow.Lahdensivu and Aromaa. (2015), the occurrence of ASR problem will still persist if there is moisture still around the deteriorating structure. It may therefore be good practice to stop its occurrence by applying waterproofing.. All materials making up the concrete need to be analysed and contribution to deterioration of such structures monitored.

An area to study is the composition of sea water with respect to Alkali Silica reactions in which for places like lagos which are surrounded by water, structures could be exposed to a lot of Alkali Silica reacting material and hence this could result in a lot of damage on the structures. This would turn out to be costly.

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