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Investigation of Potential Alkali-Carbonate Reaction in Carbonate Rocks by Rock Cylinder Method

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***Abstract*— Alkali Carbonate Reaction (ACR) may occur in concrete having dolomitic aggregates and will have deterrent effects on the concrete structures. So, the investigation becomes necessary before its application in concrete. As we know that the occurrence of ACR will depend upon the mineralogy of the rock. So, in this paper, along with the ACR test (by rock Cylinder Method), X-ray Diffraction (XRD) is also done on dolomitic rock from five different quarries of Northen India. Through XRD, it is found that the mineralogical composition of the samples from five quarries were different. The analysis of RCM results revealed that the percentage change in the length varied from -0.0368 to -0.974%. When the two studies were brought together, it is found that the percentage change in length of the rock cylinder (through Rock Cylinder Method) is proportional to the percentage of Calcium Magnessium Carbonate Dolomite present in the rock.**

***Index Terms*—Alkali Carbonate Reactivity (ACR), Aggregate, Rock Cylinder, Expansion**

I. INTRODUCTION

The alkali aggregate reaction is a chemical process in which certain mineralogical components of the aggregate react with dissolved alkaline hydroxides in concrete solution. Alkali carbonate reaction (ACR) is one of the types of alkali aggregate reaction, depending on the mineralogy of the rock. The ACR is attributed to the presence of dolomite from calcite dolomites and dolomitic limestone [1]. In 1957 Swenson and then Gillot I.E. (1964) and Dunkan M.A.G. et al. (1973) described some of the carbonate rocks from Kingston in Ontario (Canada) which, when used in concrete, demonstrate destructive expansion. This process differed from the Stanton process of alkali-silica reactions and was characterized by the dolomite decay as an effect of its reaction with alkalis. Swenson named this process the dedolomitization reaction.

II. MECHANISM OF ACR

Dedolomitization, or the breaking down of dolomite, is normally associated with expansive ACR [2]. Concrete that contains dolomite and has expanded also contains brucite (magnesium hydroxide, Mg (OH) $_2$), which is formed by dedolomitization. Dedolomitization proceeds according to the following equation [3]:

$$CaMg(CO_3)_2 + 2MOH \rightarrow Mg(OH)_2 + CaCO_3 + M_2CO_3$$
(Dolomite) (brucite) (Calcite)

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Where M represents Na, K or Li in concrete, the final product M_2CO_3 component may react with $Ca(OH)_2$ from hydration of cement to regenerate alkali hydroxide:

$$M_2CO_3 + Ca(OH)_2 \longrightarrow 2MOH + CaCO_3$$

The dedolomitization reaction and subsequent crystallization of brucite may cause considerable expansion. Whether dedolomitization causes expansion directly or indirectly, it's usually a prerequisite to other expansive processes [4].

Reactive rocks usually contain larger crystals of dolomite scattered in the core and surrounded by a fine-grained matrix of calcite and clay. Calcite is one of the mineral forms of calcium carbonate; dolomite is the common name for calcium-magnesium carbonate. Aggregate susceptible to ACR reaction are usually unsuitable for use in concrete structures for other reasons-strength potential etc [5]

Alkali reactivity of carbonate rocks is not usually dependent on clay mineral composition [2]. Aggregates have potential for expansive ACR if the following lithological characteristics exist [3,6]

- Clay content, or insoluble residue content, in the range of 5% to 25%;
- Calcite-to-dolomite ratio of approximately 1:1;
- Increase in the dolomite volume up to a point at which interlocking texture becomes a restraining factor;
- Small size of the distance dolomite crystals (rhombs) suspended in a clay matrix.

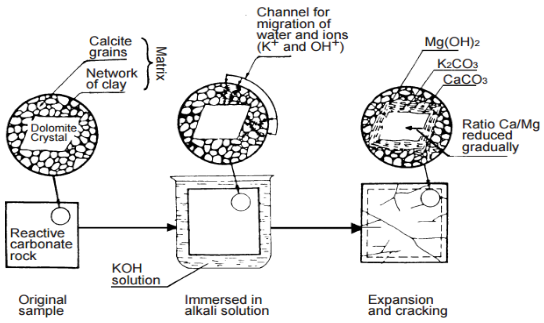

Fig 1: Schematic diagram of the mechanism of alkali-carbonate reaction. A dolomite crystal combines with alkalies in solution to form brucite and potassium and calcium carbonates. [7]

Process of ACR is illustrated in the fig 1. Expansion may be due to a combination of migration of alkali ions and water molecules into the restricted space of the fine-grained matrix surrounding the dolomite rhomb. Migration of these materials into the rhomb and rearrangement of the dedolomitization products, especially brucite, which exerts pressures as it crystallizes [7]. Expansion and map cracking of concrete as shown in Fig 2.

Fig 2: Photograph of typical surface map-cracking due to ACR (Ref. ACI 22.1R-98) [8]

III. TEST METHODS TO EVALUATE POTENTIAL FOR ALKALI CARBONATE REACTION DISTRESS

Investigations of concrete deterioration resulting from ACR have provided several techniques and criteria for evaluating the potential of aggregate to participate in this reaction in expansive concrete. It is evident that destructive ACR is resulting from the formation of Brucite. Its presence must be determined to prevent the distress due to ACR. There are three test methods commonly used for identification of ACR. The following tests are commonly used for identifying the ACR distress in addition to the Rock Cylinder Method which is used in this paper for the investigation.

- Field Service Record
- Petrographic Examination
- Concrete Prism Method
- Rock Cylinder Method

Field Service Record

Field service record of the aggregate is a very important parameter to assess the suitability of the aggregate to be used, if available. The similarity of the environmental conditions and structure to the proposed construction must be evaluated. Field service records, when available, can provide the direct response to the question: Will concrete containing this aggregate suffer distress from ACR in its intended service environment that will significantly reduce its service life? [8]. However to provide a definitive answer this must be supplemented by other test methods.

Petrographic Examination

Petrographic examination is very important from the ACR point of view. Petrographic examination of the aggregates determines if their lithologic characteristics match with the representative of reactive carbonate rocks. This examination is an important part of any evaluation of aggregates for concrete, and should be performed by an individual qualified by education and experience. Guidance on performing petrographic examinations is provided in ASTM C 295. Because of the variability of lithologic characteristics in rock units, the sampling of aggregates for evaluation purposes is quite important and should be performed with care. Good sampling procedures are discussed in ASTM C 295[8].

Concrete Prism Method

It is generally recognized that concrete prism method provides the best indication of potential for deleterious expansion of a carbonate aggregate in concrete. The two methods use a similar size of test specimen. ASTM C 1105 specifies moist storage at 23 deg C while CSA A 23.2-14A specifies moist storage at 38 deg C. Work by Rogers and Hooton (1992) indicates that storage at 38 deg C gives a better prediction of the long-term expansion of field concrete. These methods differ in how they approach the issues of alkali content of the mixture and the aggregate gradation. Because these two factors influence the amount of expansion that results from the ACR, care must be taken in evaluating and comparing the results and criteria of the two methods [8]

Rock Cylinder Method

The rock cylinder method as per the ASTM C 586 covers the determination of the expansion of a specimen of carbonate rock while immersed in a solution of 1N NaOH solution at room temperature. This test method is intended to give a relatively rapid indication of the potential expansive reactivity of certain carbonate rocks that may be used as concrete aggregates. ASTM C 586 recommends the test specimens should be examined petrographically to be sure they are representative of the lithologic characteristics of the rock being evaluated [9]. As described in ASTM C 586, the test provides a relatively rapid indication of potential expansive reactivity and is an effective tool for screening aggregate sources.

ACR by Rock Cylinder Method (as per ASTM C 586) also require longer duration for test but as per the code usually expansive tendencies are evident after 28 days of immersion in alkali solution.The expansive behavior of aggregate in concrete is qualitatively predicted by the results of the rock cylinder test. Quantitative prediction of the expansion of concrete containing reactive aggregate depends upon (1) the degree of aggregate reactivity, (2) the amount of reactive constituent, (3) the alkali content of the cement, and (4) the environment. Appreciable expansion should indicate the need for further testing.

As per the code, expansion in excess of 0.10% is indicative of chemical reaction and should warrant additional testing preferably in concrete using test method as per “Standard Test Method for length Change of Concrete Due to Alkali-Carbonate Rock Reaction (ASTM C1105), [10]. If the expansion is less than 0.10% at 28 days, expansion reading shall be continued for one year.

IV. LABORATORY INVESTIGATION AND DISCUSIONS

XRD

X-ray diffraction method has been used for determine the type of rocks or identification of the unknown crystalline materials present in it. Before determining whether the rock is ACR reactive or not first we have to determine the type of rock as it is clearly evident from the several literatures that the calcitic /dolomitic rocks are generally ACR reactive [8].

The results from the XRD analyses of rock are presented in Table 1 and Fig 3.

Table 1: Mineralogical Composition of different QUARRY by X-Ray Diffraction Method

Quarry	XRD Classification	
	Minerals	**%**
QUARRY-A	Calcium Magnesium Carbonate (Dolomite)	100
QUARRY-B	Calcium Carbonate Calcite	58.2
	Calcium Magnesium Carbonate (Dolomite)	30.8
	Silicon Oxide Quartz, low	11.0
QUARRY-C	Calcium Carbonate Calcite, Syn	62.3
	Calcium Magnesium Carbonate	27.4
	Silicon Oxide Quartz, Syn	10.3
QUARRY-D	Calcium Magnesium Carbonate (Dolomite)	42.5
	Calcium Carbonate Calcite	33.4
	Silicon Oxide Quartz, low Syn	24.1
QUARRY-E	Calcium Magnesium Carbonate (Dolomite)	67.3
	Silicon Oxide Quartz,	32.7

Rock samples from Quarry A consist of Calcium Magnesium Carbonate Dolomite up to 100% which is presented in Fig 3 (a)

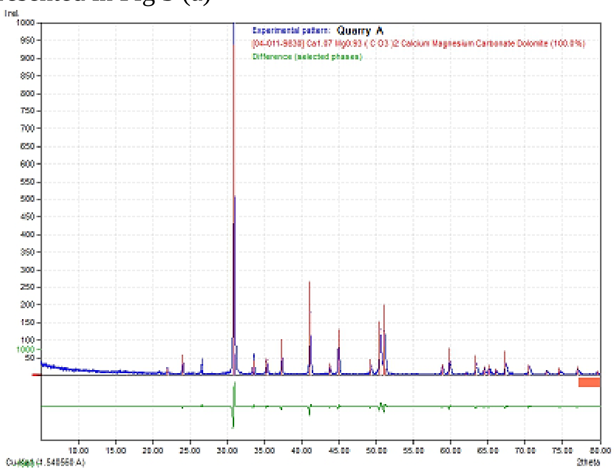

Fig. 3 (a)

Rock samples from Quarry B consist of predominantly Calcium Carbonate Calcite up to 58.2 %, Calcium Magnesium Carbonate Dolomite up to 30.8% and Silicon Oxide Quartz up to 11.0% which is presented in Fig 3(b)

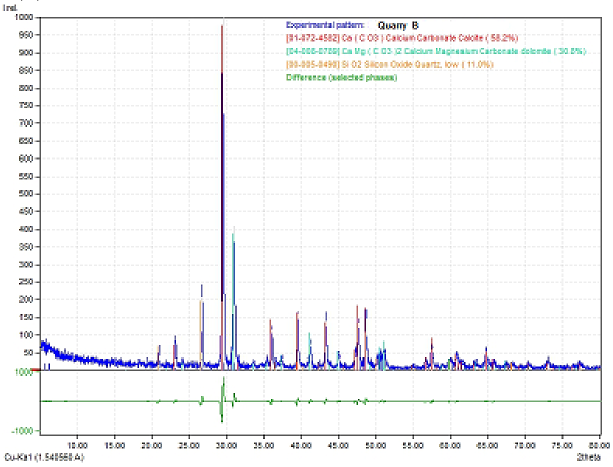

Fig. 3 (b)

Rock samples from Quarry C consist of predominantly Calcium Carbonate Calcite up to 62.3 %, Calcium Magnesium Carbonate up to 27.4 % and Silicon Oxide Quartz up to 10.3% which is presented in Fig 3 (c).

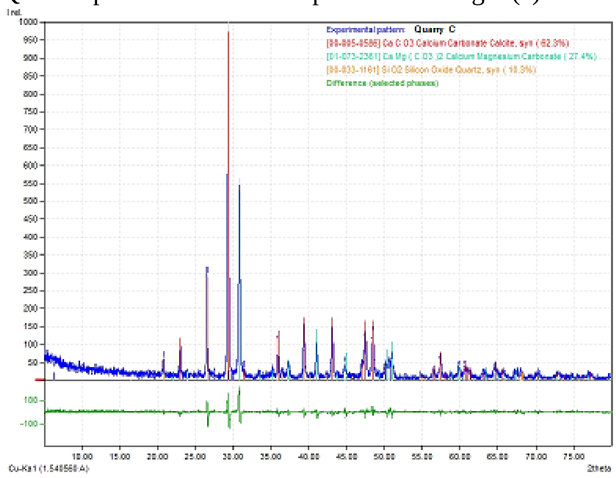

Fig. 3 (c)

Rock samples from Quarry D consist of predominantly Calcium Magnesium Carbonate Dolomite up to 42.5 %, Calcium Carbonate Calcite up to 33.4 % and Silicon Oxide Quartz up to 24.1% which is presented in Fig 3 (d).

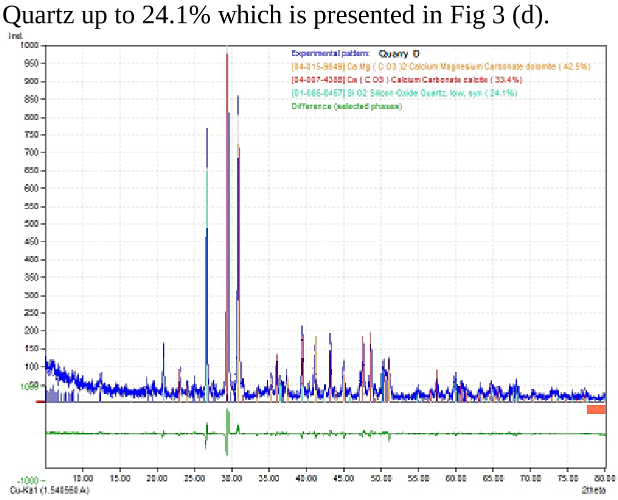

Fig. 3 (d)

Rock samples from Quarry E consist of predominantly Calcium Magnesium Carbonate Dolomite up to 67.3 % and Silicon Oxide Quartz up to 32.7% which is presented in Fig 3 (e).

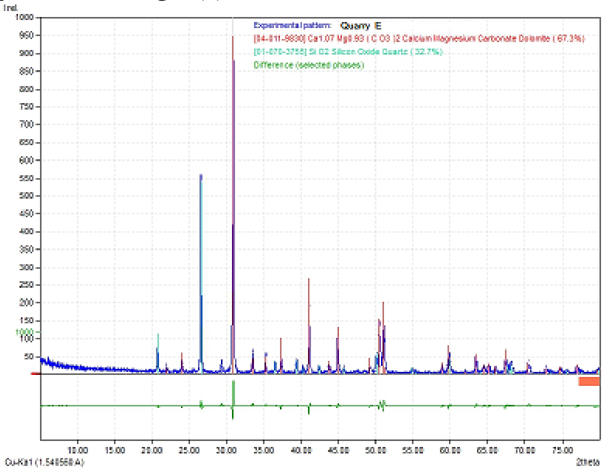

Fig. 3 (e)

Fig 3: 2-D Diffraction patterns showing concentric rings of scattering peaks for identifying the materials

The dolomite appears as the major component (up to 100% in one sample) followed by calcite (about 62.3 %). Silicon Oxide quartz occur in all (except one rock sample) analyzed rock samples.

The five representative samples collected from different quarries for one of the project in J & K was assessed by XRD method. After the XRD analysis of the rock samples it was found that the rock type was predominantly calcitic/ dolomitic. Thus the expansive behaviour of such type of rocks can be determined if Alkali Carbonate Reaction takes place. Alkali Carbonate Reaction can be determined by several methods but in this paper Rock Cylinder Method (as per ASTM C 586), [8] has been used to determine it.

ALKALI CARBONATE REACTIVITY TEST (BY ROCK CYLINDER METHOD)

In the rock cylinder method, the test specimen of an overall length of 35±5 mm and a diameter of 9±1 mm, in the form of right circular cylinders with plane parallel ends has been prepared and is used for the testing. Specimen cylinders have been immersed in the distilled water at a room temperature in the range of 20 to 27.5°C. The reference length (initial reading) for calculating the length change, achieved after 1 to 4 days of immersion. After the reference length was achieved, the specimens were kept in 1N NaOH solution at room temperature in a sealed container. Measured the length of the cylindrical specimen after 7, 14, 21 and 28 days (as shown in fig 4) of immersion in NaOH solution and at 4-week intervals thereafter, if required.

MINEROLOGY OF ROCKS V/S EXPANSION

To find the effect of mineralogy of rock on the expansion of rock cylinder, the graph and table is drawn and presented as Fig 5 and Table 2 respectively

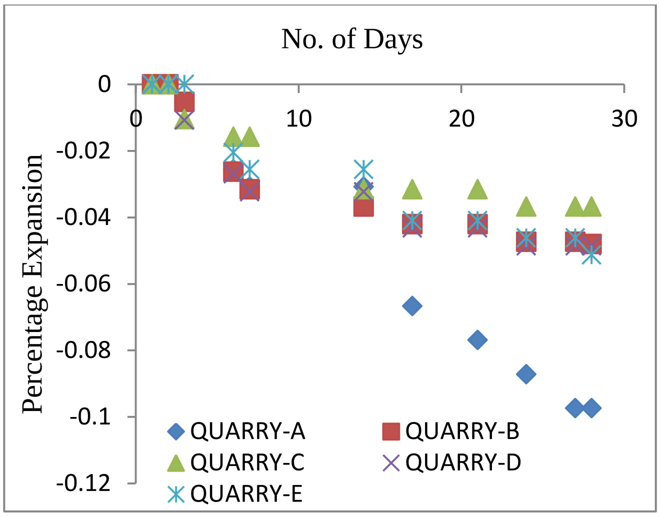

Fig 4: Percentage Expansion v/s No. Of Days

Table 2: Mineralogical Composition and percentage expansion of samples from different QUARRY

QUARRY NAME	Calcium Magnesium Carbonate (Dolomitic) % present in quarry	Percentage Expansion of rock cylinder at 28 days
A	100	-0.0974
B	30.8	-0.0480
C	27.4	-0.0368
D	42.5	-0.0486
E	67.3	-0.0513

The expansion was found negative in all rock samples during the testing time of 28 days in place of positive expansion. And thus it is much below the expansion limit of 0.10% at 28 days as per the relevant standards. It can be due to the contraction of rocks or due to the disintegration of rock minerals in NaOH solution.

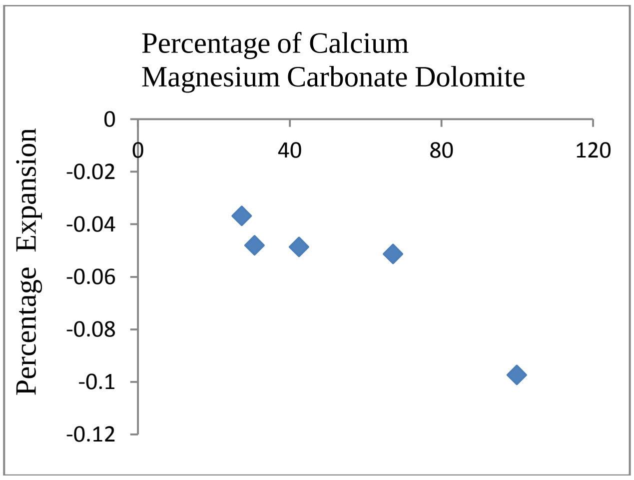

Fig 5: Percentage Expansion V/s Calcium Magnesium Carbonate Dolomitic % in QUARRIES

It can be seen from Table 2 and Fig 5 in which the relations for mineralogy of rock samples and the expansion at 28 days have been shown that as the percentage of Calcium Magnesium Carbonate Dolomite increases the decrease in length also increases. It is also observed from the graph that when the percentage of Calcium Magnesium Carbonate Dolomite increases beyond 67.3 %, the decrease in length is sharply increased

V. CONCLUSION

Rock cylinder method is an effective tool for rapid (in comparison to other ACR test method) screening of the aggregate sources. The percentage change in length is proportional to the percentage of calcium magnesium carbonate dolomite. This implies that expansion in ACR is highly affected by the mineralogical composition of the rock and therefore XRD analysis can give early vital information on ACR Expansion.

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