A Critique on the Petrographic Detection of Potentially Deleterious Minerals in Aggregates and its Significance in Engineering Geological Studies in Indian Context

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Abstract

Aggregate together with lime – alkali paste (cement) forms the fundamental framework of any concrete structure. Presence of certain minerals and their forms destabilizes the concrete structures over a period of time. The main deleterious materials are certain forms of silica. Dolomite can also be a major deleterious material in the aggregates. These materials deleterious in the sense, they react with alkali hydroxides of the cement and cause expansion and cracking over a period of time. Reactive minerals and their forms can be identified by petrographic examination. Petrographic detection of deleterious minerals in aggregates is cost effective; can be done with in a short time and can be performed as a first step to screen the aggregates for concretes before proceeding for elaborate tests.

Introduction

Certain minerals and their forms which are part and parcel of rocks can be deleterious by their mere presence it self in the sense they react with lime -alkali paste with which a rock aggregate is mixed over a period of time the time taken could be few years to few tens of years depending on the material used and the climate in which the structure is subjected to.

The conditions required for reactions to take place are

- High alkali containing cement.
- A reactive aggregate.
- Presence of water.

In India as most of the aggregate used in the construction of concrete structures, barring Deccan basalts, mostly comes from granitic/ gneissic terrain, which bear poly phase deformational and metamorphic imprints, and the sedimentaries derived from them. Un deformed granite bodies have very restricted occurrence in India, which can generate ideal aggregate for concrete structures. Percentage of quartz in granitic/ gneisses ranges from 20% to 60%, which could have a bearing on in their suitability as aggregate, if the rock is deformed. If quartzites are to be used as aggregate, the problem compounds because the rock itself comprised of quartz. In many cases apparently un- deformed- massive or weakly foliated rock body may have taken good amount of strain during its emplacement or subsequent to its emplacement due to compressional or tensional forces or a combination of two. Such deformational imprints particularly hazardous to construction industry are registered in quartz. Simple petrographic examination can aid in the detection of potentially deleterious or hazardous minerals and their forms and the quantity of hazardous material present in the rock meant to be aggregate. Therefore in the Indian context, the identification of reactive minerals and their forms by critical petrographic evaluation techniques assume a greater importance.

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Petrographic detection of deleterious minerals and their forms

Potentially deleterious reactive silica forms in aggregates include, highly strained quartz crystals, amorphous silica (silica glass), cryptocrystalline quartz, microcrystalline, chert and opal. In general strained quartz is identified by its characteristic unulatory extinction under petrological microscope. Amorphous silica is non-crystalline silica, which is also called as silica glass. This appears dark under microscope. Cryptocrystalline quartz is incipiently crystallized silica, which has indistinguishable structure under microscope. Microcrystalline quartz is a form of quartz having extremely fine- grained structure, which can be easily identified petrographically. Opal is naturally occurring hydrous silica. It is characterized by fibrous stricture under microscope (Fig-8). Chalcedony is name given for compact varity of silica, which is charecterised, by submicroscopic pores. Chert is opaque / dull colored minute silica, which is precipitated from solution. Silica glass cryptocrystalline quartz and microcrystalline quartz are commonly present in volcanic rock aggregates. Fine-grained micas and chlorite may also cause ASR (West 1996). Presence of dolomite can be known by staining techniques. Fine-grained phyllosilicates and chlorite can be easily detected petrographically.

The reaction between the materials of aggregate with alkalis is known as alkali – aggregate reaction and it has two variants, a) Alkali – Silica reaction (ASR) and Alkali – Carbonate reaction (ACR). Apart from mere presence of reactive material some textures also may enhance the possibility of reactions. For examples, micro-fractures / dislocations and sub- grains increases the solubility, and hence the reactivity.

Alkali –Carbonate reaction (ACR) are observed in dolomitic rocks. This occurs in impure dolomites and dolomitic limestones, which contain certain amount of clay. The alkalis react with dolomite forming calcite and brucite. Dedolomitization opens micro cracks allowing water in to the system, which is absorbed by clay which swells and cause expansion similar to ASR. ACR is relatively rare because aggregates susceptible to ACR are less common and also they are not suitable in concrete for other reasons. ACR can generalised as below.

$CaMg(CO3)2 + NaOH / K2O + H2O = Mg(OH)2 + CaCo3 + Na2CO3$

Off all, strained quartz is the most ubiquitous reactive form of silica and ASR is of more concern because silicate aggregates are more commonly used in the concrete structures. In ASR, aggregates containing certain forms of silica will react with alkali hydroxides. Silicate anions detached from the reactive aggregate by hydroxyl ions from the micro pore fluids and alkali hydroxides. Sodium and potassium cations will balance the silicate anions and form alkali silicate gel. This alkali- silicate gel swells as it absorbs water and increases in volume. Expansive pressure generated by the swelling gel ruptures the concrete matrix and aggregate particles and causes cracking of the concrete. The cracking in the concrete then allows more water to infiltrate in to the concrete creating more gel and more expansion. Ultimately the concrete fails or disintegrates and destabilize the structures. Typical indicators of the ASR are random cracks and spalled concrete especially in moist areas of the structure. The generalized reaction can be given as below.

$SiO2 + NaOH / K2O + H2O = Na2SiO3.H2O / K2 SiO3.H2O$

A modified ASR is the alkali-silicate reaction; the reactive constituent in the aggregate is silica present in the combined form of fine-grained micas and chlorite

Strained quartz is identified by its characteristic undulatory extinction under petrological microscope. If a rock containing quartz is deformed, crystal lattice are bent as consequent crystallographic planes also

Photomicrographs of strained quartz grains

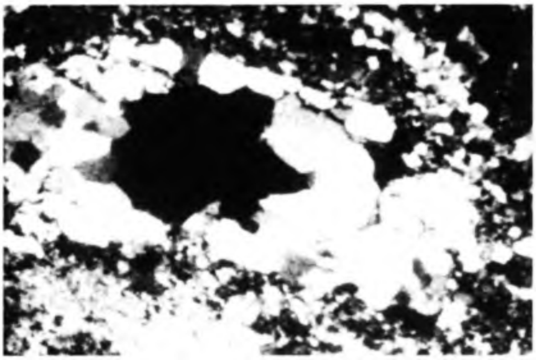

Fig. 1: Quartz crystal depicting subgrain formation along periphery (field view 2mm)

Fig. 2: Quartz crystal depicting deformational bands (field view 1.5 mm)

Fig. 3: Deformed and rotated quartz grain (field view 2 mm)

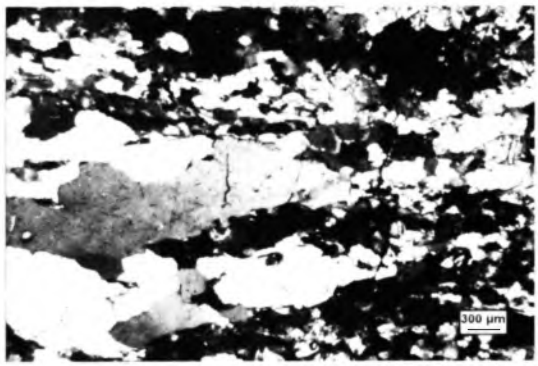

Fig.4 Deformed and stretched quartz grains

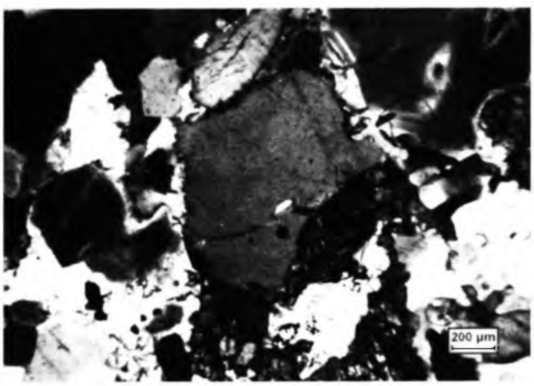

Fig. 5: Deformed quartz grains depicting granulated grain boundary

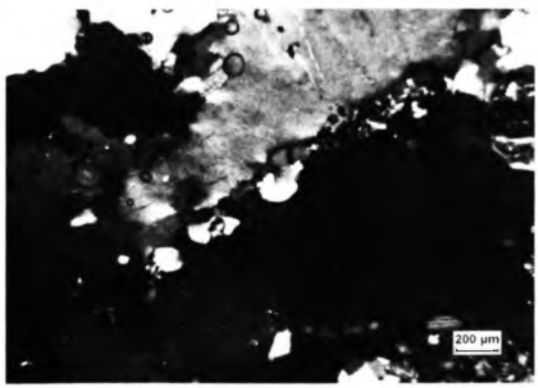

Fig. 6: Quartz grain showing granulated grain boundary

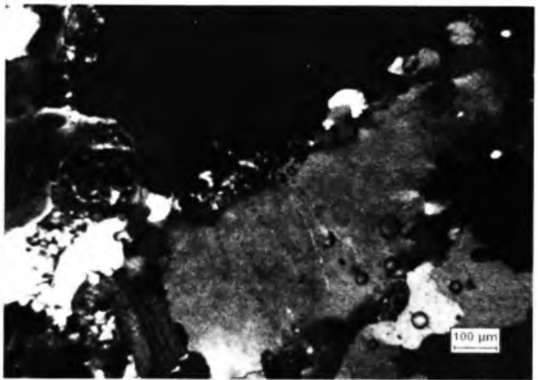

Fig.7 Quartz grain showing granulated and recrystallied grain boundary

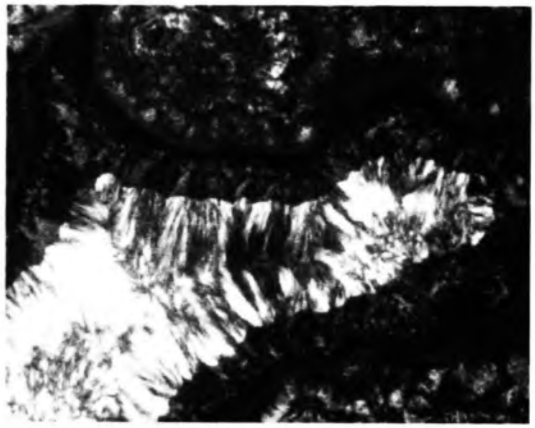

Fig.8 Photomicrograph of opal

assume curvature. The curved crystallographic planes cause the constant variation of the extinction across the grain. This is optically expressed as undulose / undulatory extinction. Stretching and recrystallisation resulting in formation of sub-grains, presence of deformational bands (Fig1-7) are usual features, which indicate strained quartz. Bi axial character of quartz is also an indicator that the quartz is strained (Deer et al., 1992)

Rocks containing more than 30% of highly strained quartz are considered as potentially reactive. (Dolar & Mantuani, 1983}. The problem lies in the quantification of amount of strain the quartz has taken. Deformation in a rock body is never a homogenous phenomenon and varies place to place from mesoscopic (outcrop scale) to microscopic scale (grain scale). Hence the selection of proper representative sample of rock body meant to be aggregate is very important. Equally important is the study of strain in thin section of a rock. In view of the grain scale inhomogenity of the strain accumulated average undulatory extinction of the quartz grains is obtained.

Intensity of strain can be known by measuring appearance and disappearance of first, last strain shadows respectively, coupled with position of maximum extinction. Quartz is considered as highly strained if the average undulatory extinction angle obtained from at least 20 separate quartz grains (whose c-axes are parallel or nearly parallel to the plane of the thin section) is more than 25^0. Rocks containing more than 30% of highly strained quartz are considered as potentially reactive. (Dolar & Mantuani, 1983}.

For the purpose of ASR, undulatory extinction of strained quartz is measured by the method proposed by Dolar & Mantuani, 1983 in which four readings of microscope stage are taken.

- Appearance of first extinction shadow: A
- Position of first maximum extinction: B
- Position of last maximum extinction: C
- Disappearance of last extinction shadow: D

The undulatory extinction is calculated by: (C-A) + D-B)/ 2

Some workers have disputed the Dolar & Mantuani method of measuring undulatory extinction and its reproducibility as Smith & Dunham (1989) and Anderson & Thalow (1989). The fact that undulatory extinction is caused by strain is indisputable. Undulatory extinction has been produced experimentally at pressures of about 138 kb (Deer et al., 1992)

Inter growth textures are also sited as possible causes for ASR. Granulation of quartz together with the presence of quartz feldspar inter growths are sited as possible factors for ASR in some granitic rocks from

India. (Rao & Sinha,1989). Role of highly kaolinised and sericitised feldspar resulting due to diuretic alterations during late stages of igneous crystallisation in reactions also needs to be investigated.

Authors opine that petrographic detection of deleterious minerals and their forms is still relevant and Dolar & Mantuani method of quantifying the straining in quartz is most practicable. Petrographic evaluation of aggregates is less time consuming and cost effective at least as a mandatory first level or preliminary screening of the aggregates.

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