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Durability of concrete containing siderite-bearing microsyenite and trachyte aggregates

R.P. Khatri *, G.W. Quick, V. Sirivivatnanon

CSIRO Manufacturing and Infrastructure Technology, P.O. Box 310, North Ryde, New South Wales 1670, Australia

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Abstract

The durability of concrete containing siderite-bearing microsyenite/trachyte aggregates has been investigated. The aggregates were from a disused Mt Gibraltar quarry and the Nattai River Cut 5 in the Bowral/Mittagong districts, 100 km south-west of Sydney in New South Wales, Australia. Laboratory and field exposures of embedded rock discs in mortar, and concrete and rock samples, conducted under controlled and measured environmental conditions, have shown the alteration of siderite secondary mineral in the Mt Gibraltar rock to iron oxides/hydroxides through oxidation processes. The rate of such alteration was generally found to be slow to moderate, but it was more profound in an alkaline environment. These findings are consistent with the theoretical desktop study of Eh–pH diagrams. Although the in situ oxidation of the siderite was visually observable, as pinhole-sized rust spots, the mobility of the iron and subsequent staining on concrete surfaces was negligible. The field inspection and subsequent petrographic study of existing concrete structures, made from siderite-bearing microsyenite/trachyte aggregates, have shown some degrees of in situ oxidation of the siderite to iron oxides/hydroxides, but no associated iron staining on concrete surfaces. No visual defects were observed in concrete structures in service for up to 80 years. Furthermore, it has been shown that the accelerated weathering techniques, developed in this study, can be used in future assessments of quarried rock during the various phases of any investigation.

Keywords: Concrete; Concrete durability; Aggregate; Siderite; Microsyenite; Trachyte; Secondary minerals

1. Introduction

Opinions are divided about the suitability of using siderite-bearing microsyenites or trachytes as a hard rock source for aggregates in concrete production. In the Bowral/Mittagong district, 100 km south-west of Sydney in New South Wales, Australia, there are several early to middle Jurassic microsyenite igneous intrusions that have been used in concrete production in the past, or are currently being assessed as a potential aggregate source. The main cause for concern, which has led to conflicting views on the potential long-term performance of this rock, is the presence of the secondary mineral siderite ($FeCO_3$). Previous studies [1–4] have indicated that siderite has the potential to oxidize under atmospheric conditions to iron oxides/hydroxides. This has led to concerns that siderite present in the aggregate of a concrete can oxidize and cause unsightly iron stains on the surface of the concrete, and/or the development of weaknesses in bond strength at the paste-aggregate interface. In the Bowral/Mittagong district, the mineral represents on average 5–15% of the rock; it is often found replacing (through deuteric alteration) the pyroxene in the rock. As the occurrence of siderite associated with any igneous deposit is rare, reference to its effect on durability of concrete in the literature is non-existent.

The rocks used in this study were sourced from a disused quarry at Mt Gibraltar near Bowral, and the Nattai River Cut 5 located on the Mittagong Bypass. The Mt Gibraltar rock was a typical microsyenite from the region (except for the presence of accessory chalcedony), while the rock sourced from the Nattai River Cut 5 was much finer

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* Corresponding author. Tel.: +61 2 96249913; fax: +61 2 96249999.
E-mail address: Radhe.Khatri@boral.com.au (R.P. Khatri).

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grained and displayed a trachytic texture. Both rocks contained siderite (10–11% by modal volume) as a secondary mineral phase replacing pyroxene.

In this study, four existing structures that have been in service from 9 to 80 years were examined visually and also petrographically to establish if there was any adverse staining and/or structural deficiencies. These structures were prepared with siderite-bearing microsyenite aggregate from Mt Gibraltar, and trachyte aggregate from the Nattai River Cut 5. Also, concrete (Mt Gibraltar rock as aggregate) and mortar samples (embedded Mt Gibraltar rock slices) were exposed in Sydney for three years to establish if the oxidation of siderite would lead to any staining. In addition, polished rock samples, and embedded rock discs in mortar and concrete slabs were subjected to accelerated exposures in a laboratory study. Subsequently, petrographic studies were carried out to establish whether siderite, as a secondary mineral in dense microsyenites and trachytes, would lead to any staining or cause any changes to the aggregate transition zone (cement–aggregate interface).

The stability of siderite in a concrete environment depends on the basicity (pH), oxidation potential (Eh) and total dissolved carbon, iron and sulphur in the pore water of the concrete. Thus, a theoretical study was also conducted to examine the effect of basicity and oxidation potential on the conversion of siderite to iron oxides/hydroxides.

2. Experimental procedure

2.1. Accelerated exposures in laboratory

To evaluate the potential for iron staining in concrete prepared from siderite-bearing aggregates, four types of specimens were tested in a range of accelerated exposures. Microsyenite rock samples were collected from a disused quarry at Mt Gibraltar, and Kulnura coarse aggregate was chosen for a control concrete. General-purpose (GP) cement was used with Nepean River coarse sand and a fine sand from the Penrith Lake Development Scheme. The following specimens were prepared:

- Mt Gibraltar polished thin rock sections (76 × 50 mm), 30 μm thick, for transmitted light petrographic study.
- Mt Gibraltar polished rock slices (76 × 50 × 10 mm), for reflected light petrographic study.
- Embedded rock discs in mortar (referred to as mortar slab), consisting of diamond-cut thin circular Mt Gibraltar rock discs of 50 mm diameter and 3 mm thick in 150 × 300 mm mortar slab 20 mm thick. The discs were embedded in such a way that each circular surface lay approximately 2–4 mm from the exposed surface of the mortar slab. The mortar has a water to cement ratio of 0.55 and a cement:coarse:fine sand ratio of 1.47:2:1. These slabs were wet cured for three days prior to exposure in standard laboratory conditions until the time of exposure.
- Concrete slabs of 20 × 300 × 300 mm were cast from laboratory-crushed Mt Gibraltar aggregate or a commercial Kulnura aggregate. Table 1 shows the mix proportions of the concrete mixtures for the preparation of the concrete slabs.

Table 1
Mix proportions of nominal grade 32 concrete mix (kg/m^3)

Mix constituents	Kulnura (control)	Mt Gibraltar
GP cement	300	320
20 mm aggregate	585	575
10 mm aggregate	585	570
Coarse sand	645	635
Fine sand	70	70
Water	165	190
Water-reducing admixture	1.86	1.85
Superplasticizer	1.69	6.00
Water/binder	0.56	0.60

It should be noted that Kulnura aggregate was used for the casting of the control concrete slabs only, and no rock slice nor thin section were tested as this rock contains no siderite. The specimens were subjected to the following exposure regimes.

2.1.1. Accelerated UV and IR radiation cycles

The weatherometer was programmed so that specimens were subjected to repeated 140 min cycles, consisting of 120 min (UV and IR) radiation with no water sprays, followed by 20 min of light water spray with UV radiation. During the radiation period, the temperature of the specimens was approximately 65 °C, falling to 23 °C during the water spray period. The concrete, mortar and rock slices were examined after various periods up to 385 days (3958 cycles) exposure, while thin sections were examined petrographically up to 319 days (3279 cycles).

2.1.2. Water wetting and drying cycles

A circulating tank system was set up in a 38 °C controlled room that allowed automatic wet and dry cycling of specimens (2 cycles a day of 1.5 h wet/10.5 h dry). The concrete, mortar and rock slices were examined after various periods of exposure up to 385 days (3958 cycles) exposure, while thin sections were examined petrographically after various periods of exposure up to 319 days (3279 cycles).

2.1.3. Salt wetting and drying cycles

A circulating tank system was set up in a 38 °C controlled room that allowed automatic wet and dry cycling of specimens (2 cycles a day of 1.5 h wet/10.5 h dry) using 3% NaCl salt solution. Polished rock slices were photographed after 154 days (308 cycles) exposure, concrete and mortar slabs after 154 days (308 cycles) and 256 days (512 cycles), while thin sections were examined petrographically after 91 days (182 cycles) and 190 days (380 cycles).