Comparative Study on Degradability Characteristics of Evaporitic and Carbonate Rocks from Al Ain, United Arab Emirates

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Abstract. The slake durability index (SDI) test is a well know and extensively used to measure the degradability behaviour of rocks especially for weak rocks like mudstone, shale, evaporites, carbonates, etc. The degradability of rocks plays a critical role in engineering design process either on or in the rock mass for safe and sustainable structures. Evaporitic and carbonate rocks are vulnerable to physical, chemical and mechanical weathering, break down, as result of wetting-drying processes during the SDI test. Evaporites and carbonates are outcropped at the surface and subsurface of the Al Ain city, which is located on the south-eastern of Abu Dhabi, capital city of the United Arab Emirates (UAE) at various level, and it is one of the rapid growing cities in the UAE. However, the detailed comparative data on the slaking behaviour of evaporites and carbonates are not available presently in the study area. Therefore, this paper provides a comparative study on the degradability characteristics of evaporitic and carbonate rocks in the city of Al Ain as well as comprehensive data for the study area. 142 rock blocks (~ 40x40x40 cm³ in size), which represent evaporitic (48 blocks) and carbonate (94 blocks) rocks were collected from various accessible either surfaces outcrops or excavated areas from the study area. 48 and 94 slake durability test samples of evaporites and carbonates were prepared and slake durability tests were performed according to the American Society for Testing and Materials (ASTM) standards. Furthermore, their compositional and textural characteristics were examined using polarized-light microscope, X-ray diffractometry (XRD), X-ray fluorescence (XRF) and scanning electron microscope (SEM). The degradability data for evaporite and carbonate rocks designate medium to very low and extremely high to very high values based on the classification after multiple cycling, I₀₁ to I₄₄ processes, respectively. The weight loss values from the first to the fourth cycles (I₀₁–I₄₄) of evaporite and carbonate samples are approximately 24–95 and 0.68–4.22 wt%. Obviously, evaporites are highly vulnerable compare to carbonates because of their differences in chemical and mineralogical structures and their reactions to the slaking fluid of distilled water. Hydration-dehydration effects on the evaporitic rocks may occur within short time compare to the carbonate rocks due to their natural occurrences. Thus, this study provide comparable and details information for the degradability characteristics of evaporitic and carbonate rocks, and likely improve the understanding of the durability of both rock types in the study area and elsewhere. Especially, such a reliable and inclusive information will compromise a practical guideline for engineers and decision makers to overcome difficulties on durability problems associated with evaporites and carbonates in the study area and elsewhere.
1. Introduction

Determination of slaking behaviour of rocks subjected to wetting and drying conditions is critical task in geotechnical engineering for safe and sustainable structures. The degradability features of rocks are generally assess with the 2nd cycle of the slake durability index test (SDI, \( I_{d2} \)) based on either American Society for Testing and Materials (ASTM) or International Society of Rock Mechanics (ISRM) standards. It is well-know that mineralogical and textural composition of rocks and features of slaking fluids have influences on durability of rocks [1–12].

Al Ain city, which is one of the fast growing cities in the United Arab Emirates (UAE), is located on the south-eastern of Abu Dhabi, capital city of the UAE (Figure 1). In the city and surrounding areas, evaporitic and carbonate, rocks are outcropped at various level of surfaces and subsurface. Presently, the detailed and comparative data on the slaking behaviour of evaporites and carbonates are not available in the study area. Therefore, it would be essential to provide detailed insight of the slaking characteristics of both rock types for planning, safety and sustainability of constructions sectors.

![Figure 1](image.png)

**Figure 1.** Location, sampling sites and geological map of the study area.

In literature, recognizable foundation related problems caused by evaporitic and carbonate rocks have been exclusively reported due to their natural characteristics of slaking behavior [4–6, 9–10, 13–21]. All studies, in general, are strongly recommended to pay attention when dealing with evaporitic and carbonate rocks at foundation level because of their high solubility, mineralogical and textural variability characteristics that have great effects on engineering safety, design and applications process.
Therefore, the aim of this study is to present a comparative study on the degradability features of evaporitic and carbonate rocks outcropped in the city of Al Ain with their compositional and textural characteristics and discuss their possible relationships. Furthermore, the weight loss values from the first to the fourth cycles \((I_{a1}–I_{a4})\) of evaporites and carbonate rocks are estimated by wt%. This data are new and exclusive in comparison of both rock types and may a practical guideline for engineers and decision makers to overcome difficulties on durability problems associated with evaporites and carbonates in the study area and elsewhere.

2. Study area, geological settings and rock sampling

The study area is one of the fast growing cities in the Abu Dhabi Emirate, UAE (Figure 1). Due to rapid urbanization, the city has been facing various geotechnical problems such as cavities, settlements, etc. developed in either evaporites or carbonates bedrocks in the region.

The geology of the study area is well represented by Jabal Hafit Mountain, which provides a large doubly plunging highly asymmetric anticline. Exclusive exposes of Tertiary carbonate rocks from oldest to the youngest are the Rus Formation (Early Eocene), the Damman Formation (Middle to late Eocene), and the Asmari Formation (Early Oligocene). However, only the Rus Formation was considered for this study as carbonate rocks [9]. Evaporites are represented by the Lower Fars Formation (Early Miocene) which are well exposed in a quarry northeast of Jabal Hafit Mountain [4] (Figure 1).

Forty-eight evaporitic and ninety-four carbonate rock samples, which are representative and various size (~0.40 x 0.40 x 0.40 m³) were collected from eight different locations (Figure 1). During the sampling, each sample was carefully inspected for visible fractures, veins, fillings etc. to avoid anisotropic effects. The samples were brought to the laboratory for the mineralogical and textural inspections and the SDI test samples preparation.

3. Mineralogical and textural studies

The detailed mineralogical and textural properties of both evaporitic and carbonate rock samples were first carefully studied on representative thin sections using plane and cross-polarized light microscope. Then, the same representative samples, which were pulverized aliquot, were subjected to X–ray fluorescence (XRF), X–ray diffractions (XRD), and scanning electron microscope analyses.

3.1. Gypsum

Based on the macroscopic examination of gypsum samples, in general, the gypsum could be categorized as; platy, radiating and relatively aggregated crystals gypsum, granular aggregate and prismatic crystalline gypsum, and platy to acicular and fibrous crystals gypsum [5, 6]. Well crystalline platy gypsum with minor fibrous muddy anhydrite showing folded lamination and large crystalline gypsum sucrose milky white crystals are clearly seen in Figures 2 E13–a1 and E26–b1. Furthermore, the SEM and XRD analyses are illustrated in Figure 2 E13–a2 and b2, and Figure 2 E26–a3 and b3. The SEM and XRF examinations revealed that celestite crystals traces were seen in all samples [5, 6]. The XRD analyses indicated that the gypsum contained more than 95% muddy dolomite and less than 5% of various types of anhydrite (Table 1) [5, 6].

3.2. Carbonates

The thin section examinations of carbonate samples clearly indicated the variation in carbonate rocks as; lime mud with very rare *Nodosaria* and coiled planktonic foraminifera in Figure 3 C4–a1, dolomite with lime mud, no fossils in Figure 3 C5–b1, lime mud with rich fossils large foraminifera *Somalina*, Nummulites, Mililolide foraminifera, *Globigerina* and corals in Figure 3 C10–c1, lime mud with very rich large foraminifera *Alveolina*, *Nummulites*, and Mililolide foraminifera, corals in Figure 3 C13–d1, calcite-filling fractures with large foraminifera, *Alveolina* in Figure 3 C17–e1, lime mud, recrystallized highly fossiliferous with small *Nummulites* filled with mud in Figure 3 C19–f1, and lime mud with
planktic foraminifera in Figure 3 C25–g1. The SEM and XRD analyses are demonstrated in Figures 3 C4–25-(a2–a3, b2–b3, c2–c3, d2–d3, e2–e3, f2–f3, and g2–g3). In general, the SEM examinations indicated packstone features with small intercrystalline pores and less authigenic quartz distributed among the micritic calcite [4]. The XRD analyses showed that carbonates were nearly pure calcite aggregates with more than 97% of CaCO₃ [4] (Table 1).

Figure 2. Evaporite sample of #13 (E13) and 26 (E26). Thin-section images under cross-polarized light showing; well crystalline platy gypsum with minor fibrous muddy anhydrite showing folded lamination (a1) and large crystalline gypsum sucrose milky white crystals (b1). SEM images showing; micro-rhombi prismatic crystals (a2 and b2). XRD showing identified minerals (a3 and b3).

4. Slake durability test
The SDI test samples of forty-eight from evaporitic and ninety-four from carbonate rocks, which were collected from eight different locations (Figure 1 and Table 1), were prepared based on the ASTM standard [11]. All SDI tests were performed accordingly [11] (Ex: see Figure 4 and 5) using distilled water as the slaking fluid and classified based Franklin and Chandra [1] from the 1st cycle to the 4th cycle (I₁–I₄) (Table 2).

5. Results and discussions
The SDI test results revealed that the durability classification of evaporitic rocks vary from medium to very low after four cycles and the average weight loss was 65 wt% (Table 3). Similarly, the durability classification of carbonate rocks vary from extremely high to very high after four cycles and the average weight loss was ranging from 1.18 (location #3) to 3.03 (location #6) wt% (Table 3). Furthermore, the relationship between the number of slaking cycles and the slake durability % is illustrated in Figure 6, which shows the durability features of the evaporitic and carbonate rocks collected from the study area. Evidently, evaporites are highly weak compare to carbonates due to their differences in chemical and mineralogical structures and their reactions to the slaking fluid. Hydration-dehydration effects on the evaporitic rocks may occur within short time compare to the carbonate rocks due to their natural occurrences.
Table 1: Chemical composition of representative evaporite and carbonate samples.

| Sample ID # | Location # | Sample # | CaO (wt. %) | SO₃ (wt. %) | Na₂O (wt. %) | MgO (wt. %) | Al₂O₃ (wt. %) | SiO₂ (wt. %) | P₂O₅ (wt. %) | K₂O (wt. %) | Fe₂O₃ (wt. %) | TiO₂ (wt. %) | Ti (wt. %) | Cl (wt. %) | MnO (wt. %) |
|-------------|-------------|-----------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|--------------|-------------|-----------|-----------|-------------|
| Evaporitic Rocks | 1 | E13 | 33.38 | 45.10 | <0.01 | 0.41 | 0.16 | 0.45 | 0.000 | 0.03 | 0.12 | 0.01 | 0.000 | 0.07 | 0.01 |
| | | E26 | 33.19 | 44.60 | <0.01 | 0.51 | 0.19 | 0.34 | 0.000 | 0.01 | 0.13 | 0.01 | 0.000 | 0.10 | 0.01 |
| | 1 | C4 | 54.21 | <0.01 | <0.01 | 0.16 | 0.07 | 2.64 | <0.01 | 0.02 | 0.09 | 0.01 | 0.000 | <0.01 | <0.01 |
| | 2 | C5 | 50.96 | <0.01 | <0.01 | 0.12 | 0.14 | 8.29 | <0.01 | 0.03 | 0.26 | 0.01 | 0.000 | <0.01 | 0.01 |
| | 3 | C10 | 55.16 | 0.74 | <0.01 | 0.08 | 0.03 | 0.30 | <0.01 | 0.02 | 0.08 | <0.01 | 0.000 | <0.01 | <0.01 |
| Carbonate Rocks | 4 | C13 | 55.75 | 0.30 | <0.01 | 0.06 | 0.01 | 0.09 | <0.01 | <0.01 | 0.01 | <0.01 | 0.000 | <0.01 | <0.01 |
| | 5 | C17 | 55.60 | 0.20 | <0.01 | 0.08 | 0.02 | 0.13 | <0.01 | <0.01 | 0.02 | <0.01 | 0.000 | <0.01 | <0.01 |
| | 6 | C19 | 54.80 | <0.01 | <0.01 | 1.02 | 0.03 | 0.70 | <0.01 | 0.01 | 0.08 | <0.01 | 0.000 | <0.01 | <0.01 |
| | 7 | C25 | 33.56 | 0.03 | <0.01 | 0.17 | 0.32 | 37.3 | 0.03 | 1.18 | 0.68 | 0.03 | 0.000 | <0.01 | 0.01 |

Total sample = 9
Figure 3. Carbonate sample of #4 (C4), 5 (C5), 10 (C10), 13 (C13), 17 (C17), 19 (C19) and 25 (C25). Thin-section images under cross-polarized light showing; lime mud with very rare \textit{Nodosaria} and coiled planktonic foraminifera (a1), dolomite with lime mud, no fossils (b1), lime mud with rich fossils large foraminifera \textit{Somalina}, Nummulites, Miliolide foraminifera, \textit{Globigerina} and corals (c1), lime mud with very rich large foraminifera \textit{Alveolina}, Nummulites, and Miliolide foraminifera, corals (d1), calcite-filling fractures with large foraminifera, \textit{Alveolina} (e1), lime mud, recrystallized highly fossiliferous with small \textit{Nummulites} filled with mud (f1) and lime mud with planktonic foraminifera. SEM images showing; fine-grained limestone and its pores filled with clay (a2, b2, c2, d2, e2, f2, g2). XRD showing identified minerals (a3, b3, c3, d3, e3, f3, g3).
Figure 3. Continue.

Figure 4. Representative SDI test samples of evaporitic rock (E13 and E26) after 1st to 4th cycle (C1 to C4).
Figure 5. Representative SDI test samples of carbonate rock (C4, C5, C10, C13, C17, C19 and C25) after 1st to 4th cycle (C1 to C4).
### Table 2. Slake Durability Index (SDI) classification for each locations of evaporitic and carbonate rocks (Franklin and Chandra 1972) [1].

| Rock Types      | Location | # SDI test samples | Mean ID1 (%) | Classification | Mean ID2 (%) | Classification | Mean ID3 (%) | Classification | Mean ID4 (%) | Classification |
|-----------------|----------|--------------------|--------------|----------------|--------------|----------------|--------------|----------------|--------------|----------------|
| Evaporitic      | L1       | 48                 | 52.2         | Medium         | 36.3         | Low            | 29.3         | Low            | 21.5         | Very Low       |
| Total Samples   |          | 48                 |              |                |              |                |              |                |              |                |
| Carbonate       | L1       | 13                 | 99.2         | Extremely      | 98.8         | Extremely      | 98.5         | Extremely      | 98.3         | Extremely High |
|                 | L2       | 21                 | 99.0         | Extremely      | 98.5         | Extremely      | 98.2         | Extremely      | 97.9         | Extremely High |
|                 | L3       | 10                 | 99.3         | Extremely      | 98.9         | Extremely      | 98.6         | Extremely      | 98.3         | Extremely High |
|                 | L4       | 9                  | 99.2         | Extremely      | 98.8         | Extremely      | 98.5         | Extremely      | 98.2         | Extremely High |
|                 | L5       | 7                  | 98.2         | Extremely      | 97.3         | Extremely      | 96.5         | Extremely      | 95.7         | Very High to   |
|                 | L6       | 11                 | 98.2         | Extremely      | 97.3         | Extremely      | 96.5         | Extremely      | 95.7         | Very High to   |
|                 | L7       | 23                 | 98.9         | Extremely      | 98.3         | Extremely      | 97.9         | Extremely      | 97.4         | Extremely High |
| Total Samples   |          | 94                 |              |                |              |                |              |                |              |                |
Table 3. Slake durability weight loss results of the evaporitic and carbonate rocks from various locations.

| Location # | # of Samples | Weight Loss (Max. %) | Weight Loss (Min. %) | Weight Loss (Avg. %) |
|------------|--------------|----------------------|----------------------|----------------------|
| Evaporitic Rocks |          |                      |                      |                      |
| L1         | 48          | 94.86                | 23.76                | 65.20                |
| Carbonate Rocks |          |                      |                      |                      |
| L1         | 13          | 1.68                 | 0.80                 | 1.28                 |
| L2         | 21          | 2.09                 | 0.92                 | 1.55                 |
| L3         | 10          | 1.62                 | 0.68                 | 1.18                 |
| L4         | 9           | 1.71                 | 0.78                 | 1.28                 |
| L5         | 7           | 2.03                 | 0.80                 | 1.44                 |
| L6         | 11          | 4.22                 | 1.75                 | 3.03                 |
| L7         | 23          | 2.54                 | 1.07                 | 1.83                 |
| Total      | 94          |                      |                      |                      |

Figure 6. The relationship between number of slaking cycles and slaking durability, % retained, for (a) evaporitic rocks (b) carbonate rocks.
6. Conclusions
This study provides the degradability characteristics of evaporitic and carbonate rocks, which exist in the city of Al Ain at different foundation level, and allows comparing both rock types in term of their SDI tests. The results clearly indicate that the durability of both rocks is mainly controlled by their mineralogical and textural characteristics. Evaporitic rocks are more vulnerable than carbonate rocks because of their mineralogical composition, textural features and interaction with slaking fluid, which generates two main problems for construction sector: dissolution and expansion. This could be the major challenges for designers and engineers along the city and surrounding areas. The carbonate rocks are highly durable, but the existing of cavern systems and cavities, which form in long term, should be carefully investigated for safety and sustainability of structures. Consequently, this study offer comparable, details information for the degradability characteristics of evaporitic and carbonate rocks. It would be also possible to assess the slaking behaviors with mineralogical and textural characteristics as an integrated system, which likely improve our understanding of the durability of both rock types in the study area and elsewhere. Especially, such a reliable and inclusive information will compromise a practical guideline for engineers and decision makers to overcome difficulties on durability problems associated with evaporites and carbonates in the study area and other similar region.

Acknowledgments
The United Arab Emirates University, Research Affairs, funded this research under the title of UPAR 2016–31S252 program. The authors kindly express their appreciation to research assistant, technicians, undergraduate students during the field and laboratory works.

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