DOI: https://doi.org/10.5592/CO/EUROENGEO.2024.116

# COMPARATIVE STUDY ON STRENGTH CHARACTERISTICS OF CARBONATE ROCKS FROM AL AIN, ABU DHABI, UNITED ARAB EMIRATES (UAE)

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**Abstract**

Rock strength determination, whether in-situ or in laboratory, generally requires time consuming processes. Various testing methods, such as uniaxial compressive strength (UCS), point load index PLI ($I_{s(50)}$), indirect tensile strength (ITS), and Schmidt hammer (on core, $SHV_C$ or rock block samples, $SVH_{RB}$) tests are commonly used to measure rock strength in the laboratory. In this study, sixty representative blocks of carbonate rock were collected from three different locations of the study area. Of these, forty-three blocks were selected for Schmidt hammer tests ($SHV_{RB}$). NX size (54 mm) core samples from the same blocks were prepared, and the UCS, PLI ($I_{s(50)}$), and ITS tests were carried out according to ASTM (American Society for Testing and Materials) standards. The results indicate that variable correlations, strong to very weak, or absent, exist between the rock strength parameters. The best correlations found were between the mean UCS and the mean PLI ($I_{s(50)}$) ($R^2 = 0.70$), and between the mean PLI ($I_{s(50)}$) and the mean ITS ($R^2 = 0.62$). The obtained rock strength parameters may be specific to the arid environment of the investigated carbonate rocks. However, the results are useful as a guide to decision makers and engineers.

**Key words**

carbonate rocks, rock strength, uniaxial compressive strength (UCS), point load index (PLI ($I_{s(50)}$)), indirect tensile strength (ITS), Schmidt hammer on rock block sample ($SHV_{RB}$)

## 1 Introduction

Measurements of rock strength are critical data in various engineering applications. Rock strength may be defined as the inherent strength of an isotropic rock under various conditions (Hawkins, 1998). Due to the variability of carbonate rocks structures, textures and mineralogical compositions, even on the meter scale, the generalizing of an overall bulk mechanical property, such as rock strength, is a regular problem. Therefore, it is crucial to measure the rock strength through in-situ and laboratory studies (Erguler, 2009; Yilmaz, 2010; Arman et al., 2014; 2017; 2021). Rock strength measurement, either in-situ or in the laboratory environment, is a comparatively costly and time-consuming process that involves substantial efforts in rock sampling, preparation and laboratory tests. Furthermore, a large number of rock specimens must be tested in order to arrive at a representative value for a large rock exposure.

The study areas are located at the north and east of Jabal Hafit mountain, which lies southeast of Al-Ain city, Abu Dhabi, UAE. The geologic and tectonic features of Jabal Hafit are well-documented in terms of local lithology, structural features and major stress-strain fields (Arman et al., 2014; 2017; 2021; Warrack, 1996; Boukhary et al., 2003; 2005; Styles et al., 2006) (Fig. 1).

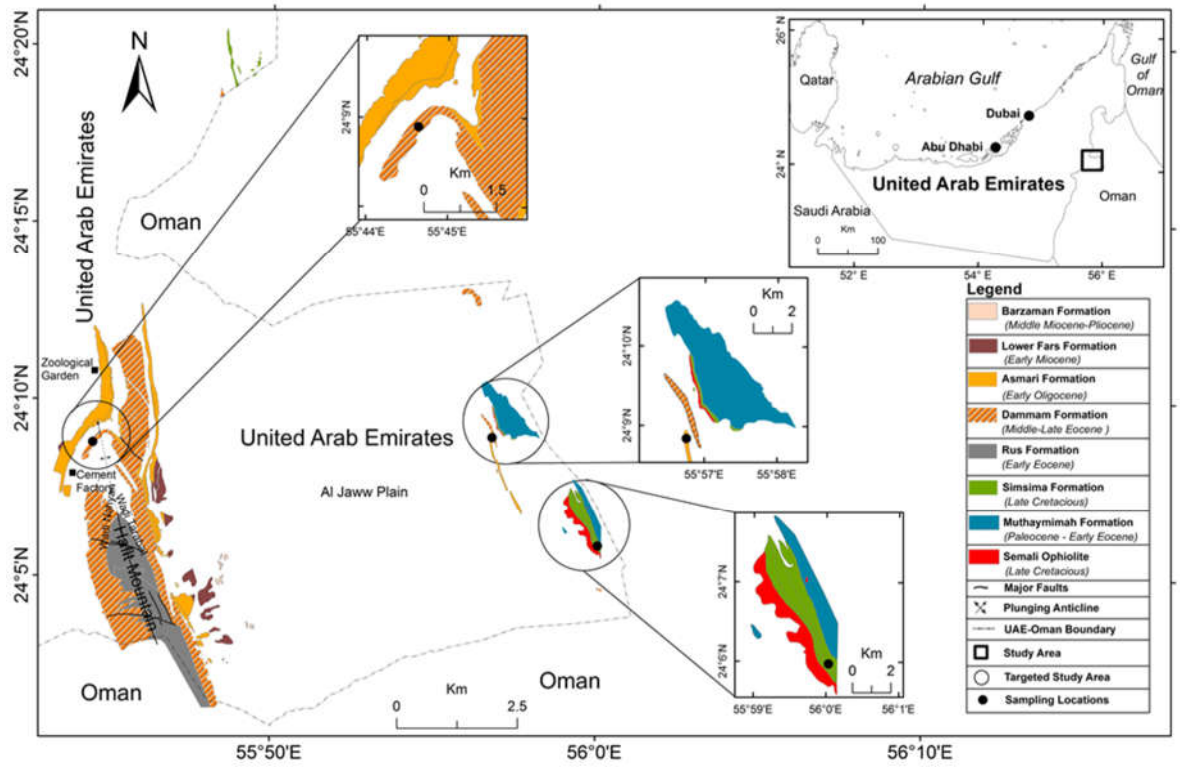


**Figure 1.** Geological map of the rock block sampling sites and surroundings.

Certain geo-engineering problems, such as slope instability, common occurrences of landslides, rock falls, paleo-karstic cavitation, etc., have been reported in Al-Ain. Carbonate rocks from the Simsima Formation (Late Cretaceous 73-65 Myr), Dammam Formation (Middle to Late Eocene 49-34 Myr) and Asmari Formation (Early Oligocene 34-29 Myr) were chosen for strength analyses, since they represent the commonest exposures of rock masses in the Al-Ain area (see Fig. 1).

In the literature, there are detailed specifications for the various available strength testing methods, including unconfined compressive strength (UCS), point load index PLI ($I_{s(50)}$), indirect tensile strength (ITS), Schmidt hammer (either on core, $SHV_C$ or rock block samples, $SVH_{RB}$). This study intends to perform laboratory strength tests of the UCS, PLI ($I_{s(50)}$), ITS and $SVH_{RB}$ on rock blocks and core samples, and derive empirical equations to describe the relations between the mean UCS and mean PLI ($I_{s(50)}$); the mean ITS and mean $SHV_{RB}$; the mean PLI ($I_{s(50)}$) against mean ITS and mean $SHV_{RB}$; and between the mean ITS and mean $SHV_{RB}$.

## 2 Experimental Studies and Results

Field trips were conducted to obtain sixty representative carbonate rock blocks samples (approximately 30x30x30 cm size) from the Simsima, Dammam and Asmari Formations from the study areas (Fig. 1, Fig. 2, and Fig. 3a). After a quality inspection of the blocks to eliminate any with visible discontinuities, fractures, filling material, etc., a subset of forty-three blocks, comprising twelve, sixteen and fifteen

from the Simsima, Dammam, and Asmari Formations, respectively, were used for Schmidt hammer tests ($SHV_{RB}$) (Fig. 3b). NX size (54 mm) core samples from the same rock blocks were drilled, trimmed, measured (sample preparations), and different strength tests of the UCS, PLI ($I_{s(50)}$), and ITS were carried out on the core samples according the suggested ASTM (American Society for Testing and Materials) standards (ASTM D5873-95, 1996; ASTM D2938-95, 1995; ASTM D5731-02, 2003; ASTM D3967-95a, 2001; ASTM D4543, 2019) (Fig. 3c-h).

**Figure 2.** A typical rock blocks from sampling sites.

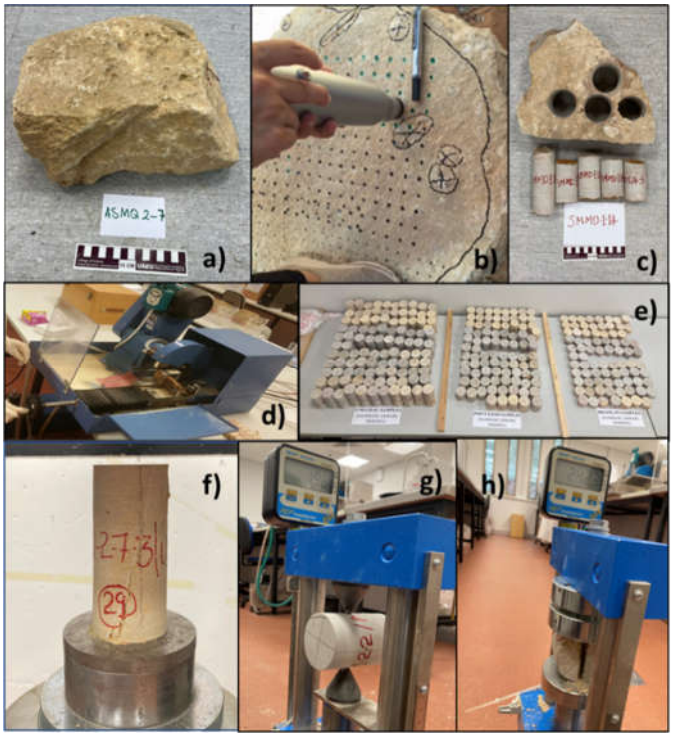


**Figure 3.** a) Rock block sample, b) Schmidt Hammer test on rock block ($SHV_{RB}$), c) Core samples with rock block, d) Core sample trimming, e) Prepared test samples, f) Uniaxial compressive strength (UCS) test, g) Point load index (PLI ($I_{s(50)}$)) test and h) Indirect tensile strength (ITS) test.

Core test samples were prepared with Length (L) / Diameter (D) ratio of 2.0 to 2.5 (for UCS), greater

than 1 (for PLI ($I_{s(50)}$), and 0.2 to 0.75 (for ITS). The loading rate for the UCS tests was 0.75 (MPa/sec) and a strain gage was not used during the test. In addition, the failure modes of the UCS tests ranged from tension, to shear, to tension + shear, and the failures were in general through the matrix. For the PLI ($I_{s(50)}$) tests, the coefficient of 1.03 was used to convert the peak load to strength. For the Schmidt hammer tests, the orientation of the rock block and hammer was 90-degree angle and the rock blocks were placed on a concrete floor that had a similar high degree of stiffness. The number of strikes that were delivered to a single point on the block to collect the Schmidt hammer data depended on the surface area of the block and was about 10 according to related standards. After collection of the strength data, the relations between the mean UCS and mean PLI ($I_{s(50)}$), the mean ITS and mean $SHV_{RB}$; the mean PLI ($I_{s(50)}$) against the mean ITS and the mean $SHV_{RB}$; and the mean ITS against the mean $SHV_{RB}$, were represented by empirical equations (Fig. 4a-f). In addition, the descriptive statistics of carbonate rocks strength tests are listed in Table 1.

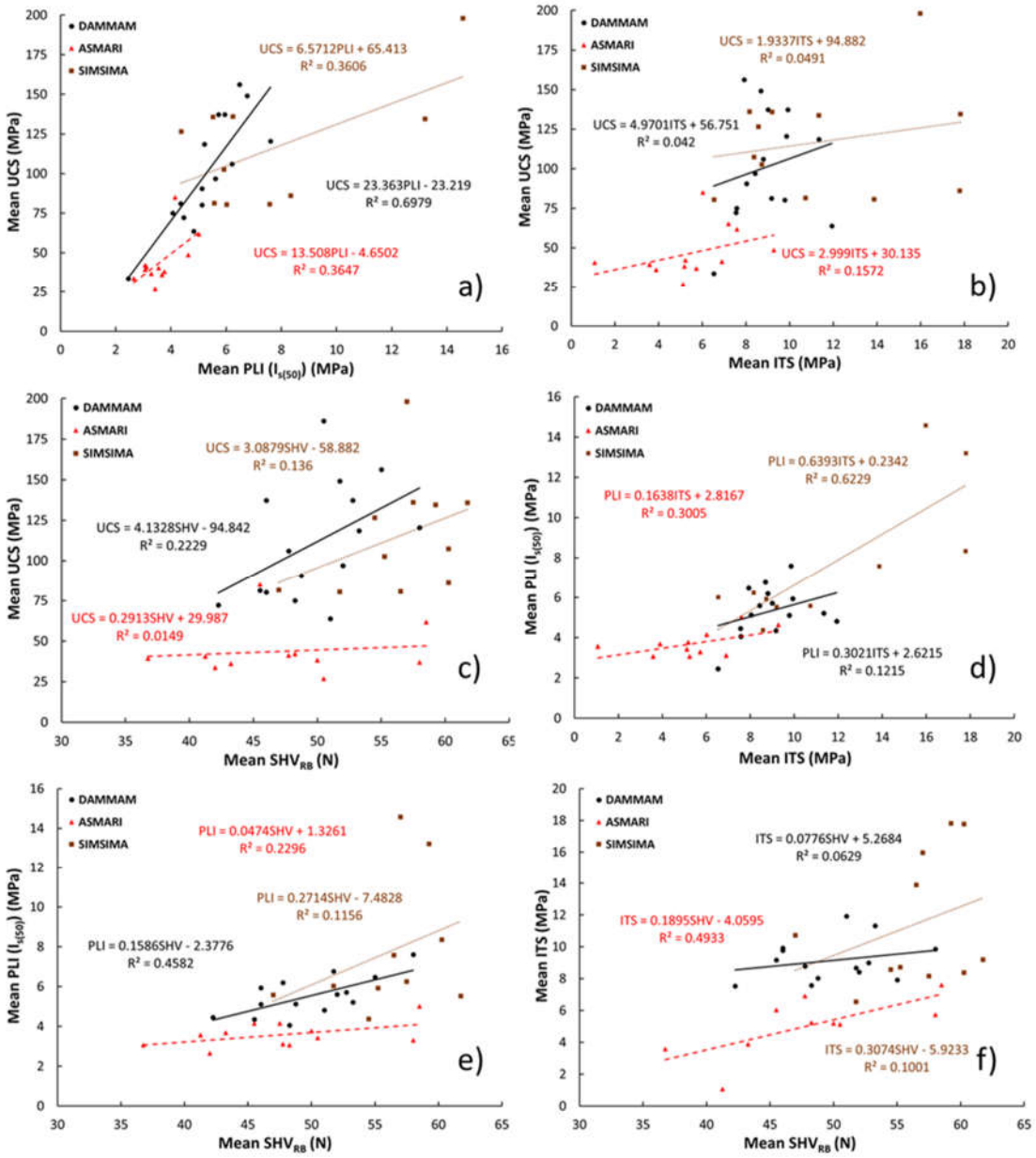


**Figure 4.** a) Mean UCS vs. mean PLI ($I_{s(50)}$), b) Mean UCS vs. mean ITS, c) Mean UCS vs. mean $SHV_{RB}$, d) Mean PLI ($I_{s(50)}$) vs. mean ITS, e) Mean PLI ($I_{s(50)}$) vs. mean $SHV_{RB}$ and f) Mean ITS vs. mean $SHV_{RB}$.

**Table 1.** Descriptive statistics of carbonate rock's strength tests

| Dammam Formation | | | | | |
|---|---|---|---|---|---|
| Test types | Number of samples | Minimum (MPa) | Maximum (MPa) | Mean (MPa) | Standard deviation |
| UCS | 51 | 33.81 | 186.14 | 106.60 | 39.86 |
| PLI ($I_{s(50)}$) | 45 | 1.69 | 7.60 | 5.15 | 1.50 |
| ITS | 39 | 4.90 | 13.48 | 9.05 | 1.92 |
| Asmari Formation | | | | | |
| UCS | 31 | 25.25 | 84.96 | 44.19 | 14 |
| PLI ($I_{s(50)}$) | 25 | 2.34 | 5.24 | 3.58 | 0.84 |
| ITS | 23 | 1.07 | 9.27 | 5.58 | 1.98 |
| Simsima Formation | | | | | |
| UCS | 22 | 42.91 | 216.41 | 126 | 46.65 |
| PLI ($I_{s(50)}$) | 18 | 4.11 | 15.07 | 7.28 | 2.92 |
| ITS | 18 | 6.54 | 23.87 | 11.21 | 4.37 |

The results revealed a full spectrum of covariances, from strong to very weak correlation, to no correlation, between the mean values of rock strength parameters with specific determination of coefficient ($R^2$) values ranging from 0.70 and 0.02. The best correlations were found to be between the mean UCS and mean PLI ($I_{s(50)}$) ($R^2 = 0.70$), and between the mean PLI ($I_{s(50)}$) and mean ITS ($R^2 = 0.62$) (see Fig. 4a and 4d). Moreover, in general, carbonate rocks from the three formations exhibited a broad range of strength behavior from moderate to strong (Simsima), weak to moderate (Dammam) and weak (Asmari) in terms of the measured various strength parameters in the study areas.

## 3 Discussions and Conclusions

This work presents a comparative study of strength characteristics for carbonate rocks of the Simsima, Dammam, and Asmari Formations, which are well-exposed in the Al Ain region, UAE. In general, the study shows that the carbonate rocks from the Simsima Formation have the highest strength value compared to carbonate rocks from the Dammam and Asmari Formations, in term of the strength tests of the UCS, PLI ($I_{s(50)}$), ITS and $SHV_{RB}$. The carbonate rocks from the three formations indicate significant variations in the various strength tests. The findings of this experimental study are unique and may provide valuable information for local authorities and engineers to guide decision-making in engineering applications, such as buildings, roads, tunnels, etc. around Al Ain city. Furthermore, this study will help to minimize or prevent environmental risks and hazards affecting the study areas and surroundings for the present and in the future. Eventually, such reliable and practical information should be considered as a preliminary study and may enable the site managers, engineer, researchers and scientists to implement more detailed investigations along the studied areas and the regions.

**Acknowledgements**
The United Arab Emirates University (UAEU), Research Affairs, funded this research under the title of SUREPLUS 2023-2024 Program. The authors wish to express their gratitude to Mr. Omer Basher and Wajeeh Kittaneh who are laboratory specialists at the Geosciences Department for sample handling, cutting, coring and trimming. In addition, this study could not be completed without the hard work and dedication of our undergraduate students.

## References

Arman, H.; Hashem, W.; El Tokhi, M.; Abdelghany, O.; Al Saiy, A. Petrographical and geomechanical properties of the Lower Oligocene Limestones from Al Ain City, United Arab Emirates. *Arabian Journal Science and Engineering.* 2014, 39, 261–271.

Arman, H.; Hashem, W.; Abdelghany, O.; Aldahan, A. Effects of lithofacies and environment on in situ and laboratory Schmidt hammer tests: a case study of carbonate rocks. *Quarterly Journal of Engineering Geology and Hydrogeology.* 2017, 50, 179–186.

Arman, H.; Abdelghany O.; Abu Saima, M.; Aldahan, A.; Mahmoud, B.; Hussein, S.; Fowler, A. Petrological control on engineering properties of carbonate rocks in arid regions. *Bulletin of Engineering Geology and the Environment*. 2021, 80, 4221–4233.

ASTM D2938-95. Standard test method for unconfined compressive strength of intact rock core specimens. 1995, 279–281.

ASTM D5873-95. Standard test method for determination of rock hardness by rebound hammer method. 1996, 693–695.

ASTM D3967-95a. Standard test method for splitting tensile strength of intact rock core specimens. 2001, 1–3.

ASTM D5731-02. Standard test method for determination of the point load strength index of rocks. 2003, 1–7.

ASTM D4543-19. Standard practices for preparing rock core as cylindrical test specimens and verifying conformance to dimensional and shape tolerances. 2019, 1–13.

Boukhary, M.; Abdelghany, O.; Bahr, S. Nummulites alsharhani n.sp. (Late Lutetian) from Jabal Hafit and Al Faiyah: Western side of the Northern Oman Mountains, United Arab Emirates. *Revue Paleobiol Geneve.* 2002, 21(2), 575-585, 1–3.

Boukhary, M.; Abdelghany, O.; Bahr, S; Hussein-Kamel, Y. Upper Eocene larger foraminifera from the Dammam Formation in the border region of United Arab Emirates and Oman. *Micropaleontology.* 2005, 51(6), 487–504.

Erguler, Z. A.; Ulusay, R. Water-induced variations in mechanical properties of clay-bearing rocks. *International Journal of Rock Mechanics and Mining Sciences.* 2009, 46, 355–370.

Hawkins, A. B. Aspects of rock strength. *Bulletin of Engineering Geology and Environment.* 1998, 57, 17–30.

Sytles, M. T.; Ellison, R. A.; Arkley, S. L. B.; Crowley, Q.; Farrant, A.; Goodenough, K. M.; Ckervey, J. A.; Pharaoh, T. C.; Philips, E. R.; Schofield, D.; Thomas, R. J. The geology and geophysics of the United Arab Emirates. Geology. *Ministry of Energy, United Arab Emirates.* 2006, 2, 1–351.

Yilmaz, I. Influence of water content on the strength and deformability of gypsum. *International Journal of Rock Mechanics and Mining Sciences.* 2010, 47, 342–347.

Warrak, M. Origin of the Hafit structure: implication for timing the Tertiary deformation in the northern Oman Mountains. *Journal of Structural Geology* 1996, 803–818.