Journal of Asian Scientific Research 3(5):506-516

Journal of Asian Scientific Research

journal homepage: http://aessweb.com/journal-detail.php?id=5003

GEOLOGICAL FEATURES AND GEOMECHANICAL PROPERTIES OF BUILDING STONES QUARRIED IN SULAIMANI CITY, KURDISTAN REGION, IRAQ

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ABSTRACT

Natural stones being used in both interior and exterior of buildings are one of the common construction materials in the world. Sulaimani surroundings in North-Estern Iraq have large natural stone reserves that can be used in different engineering purposes. For the purpose of this study, stones of limestone belonging to the Kometan Formation, including forty one samples were collected from the quarry in Chaqchaq area, in Sulaimani City. Twenty samples of them (20) were prepared as prisms of dimensions (100x100x200) mm, and the others (21) samples were cubes of dimensions (100x100x100) mm; and so, laboratory tests including thin sections for studying rock's composition, microfacies and environmental deposition. Water absorption, both dry and saturated unit weight (γ_{dry}, γ_{sat}), uniaxial compressive strength in both dry and saturated states loaded parallel and perpendicular to the bedding were performed. The results indicated that there are remarkable differences in strength and behavior of stone specimens loaded parallel to the bedding and perpendicular to it in both dry and saturated conditions.

Key Words: Bulding stone, Kometan formation, Geomechanical properties, Sulaimani, Iraq

INTRODUCTION

The Kometan Formation was defined by Dunnington, 1953, in (Bellen *et al.*, 1959) from the Komelan village. The type section is located at 400 m to the west of Kometan village in the Naudasht valley in the foothills of Qandil Mountain about 20 km to the north of Ranyia town in the Imbricated Zone (Karim *et al.*, 2008). The Kometan Formation is exposed in High and Low Folded Zones (Buday, 1980; Buday and Jassim, 1987) and it is composed of well bedded, light grey or white limestone and contains locally chert nodules with rare pyrite concretions (Karim *et al.*, 2008). The thickness of the formation, in the High Folded and Imbricated Zones, comprises 120m thin bedded globigerinal-oligosteginal limestone, locally silicified (with chert concretions in some beds), with a glauconitic bed at the base (Jassim and Buday, 2006). The formation has a similar lithology throughout the Balambo-Tanjero Zone. However, to the W and SW it becomes increasingly argillaceous. The formation also contains varying proportions of globigerinal and oligosteginal limestones.

The Kometan Formation is widespread in central, N and NE Iraq. Abundant fossils in the Kometan Formation indicate the basal beds of the formation are of Turonian age (based on the presence of Globotruncana renzi and that the overlying beds are of Santonian age (Bellen *et al.*, 1959). In the studied area (Fig. 1) the thickness of Kometan Formation reaches about 110 m, the thickness of beds ranges between 5-80 cm and consists of white limestone (Fig. 2).

For thousands of years the construction of stone buildings has been characterised by the gravitational methods employed where stone laid upon stone, the weight of each bearing onto those immediately below, with arches and lintels distributing the structural forces around openings. In this tradition, walls were the primary load bearing structural element, with piers, columns and buttresses of the same material emerging over the centuries as man sought to extend the architectural possibilities of stone construction.

Natural stones being used in both interior and exterior of buildings are one of the common construction materials in the world. These stones as construction materials should have a good quality according to their geomechanical properties (Saffet, 2010) that play an important role in planning and designing of civil constructional works when stones are used for constructing modern structures and buildings (Sharma *et al.*, 2006). Since prehistoric times, limestone has been one of the most popular types of building stone and is today used in both the construction of modern buildings and in conservation as a replacement material for the reconstruction of monuments (Kramar *et al.*, 2010). According to ASTM C 568-89 (1992) the limestone is classified into three types according to its density (Naghoj *et al.*, 2010), the limestone with density 1760-2160 kg/m^3 is considered to by soft, the medium density ranging between 2160-2560 kg/m^3 and the rock is considered to be hard, and the third type of limestone is very hard with density greater than 2560 kg/m^3

Geomechanical properties of natural stones have a crucial importance when stones are used for constructing modern structures and buildings. Therefore, field and laboratory studies are indispensable to investigate the stone quality for purposed structure (Saffet, 2010). This experimental investigation is to study the geological features in thin sections, physical and mechanical properties of natural building stone usually used in the construction of load-bearing concrete backed stone masonry walls, columns and houses in Sulaimani Governorate and other places in Kurdistan Region in Iraq.

MATERIALS AND METHODOLOGY

In this study, laboratory tests were carried out to investigate the quality of construction stones quarried in the region. Physical and mechanical properties of stone specimens were examined using common laboratory tests and accessible facilities in this study. In the first stage of the study, (41) block samples of limestone were collected from the quarry in Chaqchaq region in Sulaimani City. After that, the collected samples were subjected to the cutting machine to prepare the required specimens as shown in (Table 1).

In the second stage, all specimens were dried in an oven for 24 hours at 105C̊ to eliminate the moisture content present within them. The dry weights and dry unit weights γ_{dry} of specimens were obtained by using a balance capable of weighing to an accuracy of 0.01 g. Dry and saturated unit weights of specimens were obtained from the ratio of sample weight to the volume in kg/m^3, then the uniaxial compressive strength also was taken for half of the specimens and in two modes parallel and perpendicular to the bedding (Fig. 3), as shown in (Tables 2 and 3), while the remaining specimens were then submerged in water for 24 hours till fully saturated at room temperature. The saturated weights were obtained and then the saturated unit weights and water absorption were calculated. After that the uniaxial compressive strength tests were carried out on those specimens as shown in (Tables 2 and 3). Beside, ten thin sections were prepared for studying some microscopic geological features such as composition, microfacies, microfractures and dissolution during rock's diagenesis. The thin sections were studied under microscope.

RESULTS AND DISCUSSION

The studied thin sections under microscope indicates that the globigerinal-oligosteginal limestone analyzed in this study, consists of globigerinal oligosteginal packstone. This microfacies is dominated by oligostegins and globigerinids foraminifera, its bioclasts and calcispheres. The matrix consists mostly of dense micrite (Fig. 4). Benthic foraminifera are also present but in very rare quantities, these benthic remains probably had been transported basin wards by storm-currents. The features of planktonic foraminifera, with mud-supported matrix, scarce benthic remains, and absence of characteristic sedimentary structures in this microfacies indicate that deposition took place in the relatively open-marine and basinal environment. The abundance of planktonic foraminifers, are indicating eutrophic low-oxygenated waters (Arthur *et al.*, 1987; Luciani and M., 1999; Aguilara-Franco and Hernández, 2004).

The building stone properties including water absorption by weight, both dry and saturated unit weight, uniaxial compressive strength, parallel and perpendicular to bedding in both dry and saturated state were investigated. To evaluate the quality of studied rocks as construction and building materials, the American Society of Testing and Materials (ASTM) standards was considered. It is found that the physical and mechanical properties of investigated stones are good enough to be used for construction and buildings in accordance with the ASTM standard specification for limestone dimension stone (Table 4).

The (Tables 2 and 3) give the results of unit weight in dry and saturated conditions, water absorption and compressive strength in dry and saturated conditions and in two modes parallel and perpendicular to the bedding for studied limestones. The unit weights range from 2463 kg/m^3 to 2616 kg/m^3 in dry conditions, this means that the limestone belongs to the hard and very hard categories of limestone according to the ASTM standard specification for limestone dimension stone (Table 4). Furthermore, the water absorption is low, having the minimum values, that range between 2.1 % and 3.85 %.

The compressive strength ranges from 19.33 MPa for prism stones tested in saturated conditions when load direction was perpendicular to bedding, to 98.35 MPa for prism stones tested in dry conditions when load direction was parallel to bedding. For the cube stones, the compressive strength ranges from 35.12 MPa when the stones tested in saturated conditions and the load direction was parallel to bedding, to 108.13 MPa for stones tested in dry conditions when load direction was parallel to bedding.

There are some observations, which is, that some specimens are weaker and different than reality, due to natural defects, weathered colour, cracks and other unwanted properties such as stylolites that are formed under pressure dissolution where rocks are formed. This weakness of compressive strength after testing appears clearly on the samples number 3, 7, 11, 19, 29 and 37 (Tables 2 and 3). The macroscopic and microscopic observations on these samples confirmed that they have some small fractures and traces of stylolites, the later is very clearly in thin sections under microscope as shown in (Fig. 5), these defects cause the compressive strength decreases and for this reason, the results of compressive strength of six tests indicated by gray color in (Tables 2 and 3) were excluded and not used for the quality evaluation building stones.

The results show that the decrease of stone absorption has great significance in increasing the compressive strength of the stones, the (Table 5) clearly reveals that the compressive strength for stones tested in the dry conditions is higher than those tested in the saturated conditions. Furthermore, the (Tables 5 and 6) that contains the averages of compressive strengths in the dry and saturated conditions tested in two directions parallel and perpendicular to the bedding, indicate that the stones tested with loading parallel to the bedding have higher values of compressive strengths than those tested with loading perpendicular to the bedding. The (Table 6) also shows a comparison between the compressive strength of cubes and prisms loaded parallel and perpendicular to the bedding, the results show higher compressive strength for the cubes than for prisms. The table also gives a correction factor for converting from prism to cube and vice versa.

CONCLUSION

Forty one samples of building limestone, brought from quarry in Chaqchaq area, Sulaimani City, were used in this study. Water absorption, both dry and saturated unit weight, uniaxial compressive strength together with thin section analysis were performed to explore the quality of stones to be used for construction. The results indicated that there are remarkable differences in strength and behavior of stone specimens loaded parallel to the bedding and perpendicular to it, in both dry and wet conditions. The most important conclusions are as follows:

1. Globigerinal-oligosteginal pack stone deposited in open-marine and basinal environment was identified.
2. Higher specific weight and lower water absorption contribute to the higher strength of the stones
3. The compressive strength for limestone cubes tested in dry condition is higher than limestone cubes tested in saturated condition
4. The compressive strength for limestone prisms tested in dry condition is higher than limestone prisms tested in saturated condition
5. The compressive strength for limestone cubes and prisms tested in both dry and saturated condition loaded parallel to bedding is higher than those tested in same condition and perpendicular to bedding
6. The average of compressive strength of cubes specimens is higher than average of compressive strength of prisms in two modes: parallel and perpendicular to bedding.

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Fig-1. Chaqchaq Quarry of building stone

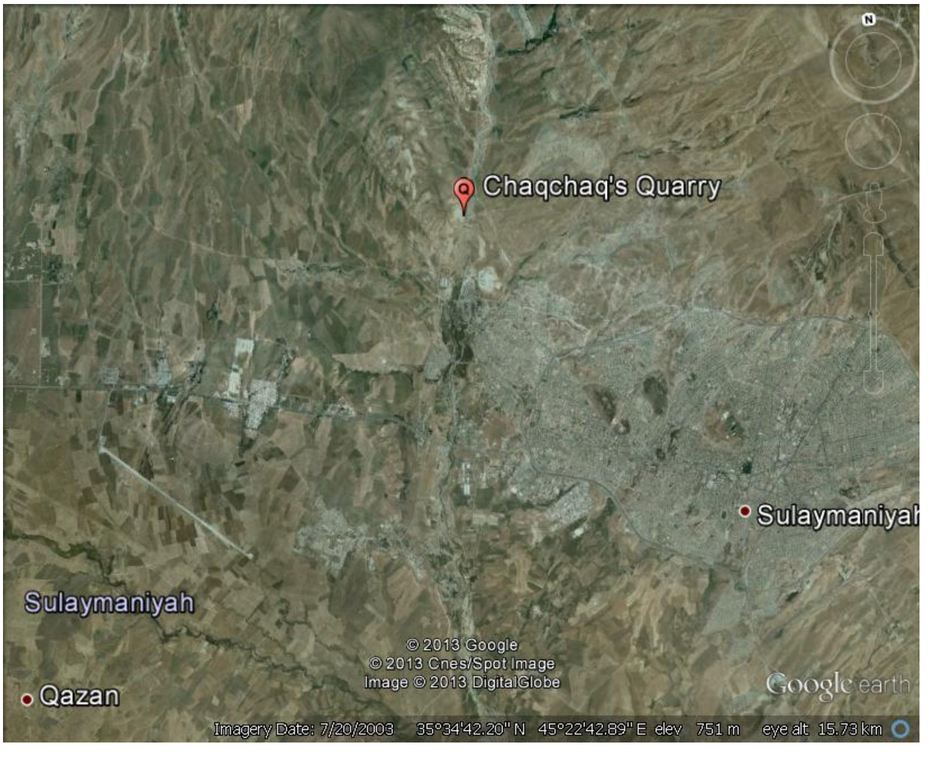

Fig-2. A section of limestone's beds in Chaqchaq Quarry showing the different thickness ranging between 5-80 cm.

Fig-3. Compressive strength parallel to bedding (A) and perpendicular to bedding (B). C and D represent the thin sections of analyzed samples and consists of fine laminated packstone with planktonic foraminifera.

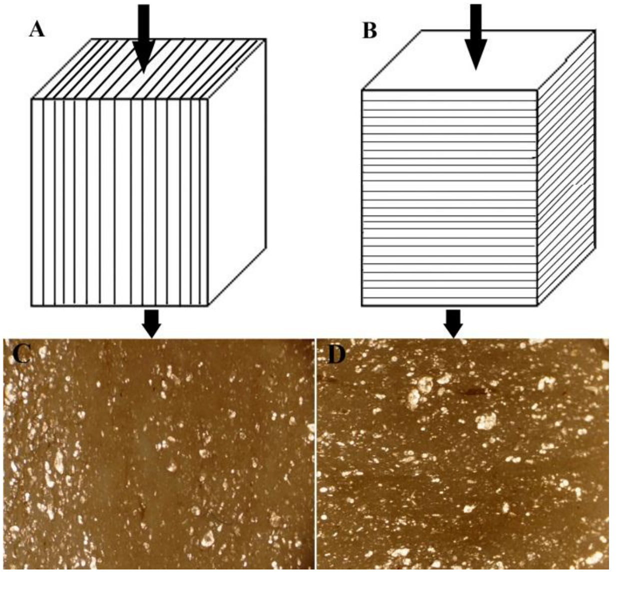

Fig-4. Photos A-F Globigerinal-oligosteginal packstone and the matrix consists completely of fine micrite. Black arrows indicate benthic foraminifera.
Scale bars equal 1 mm.

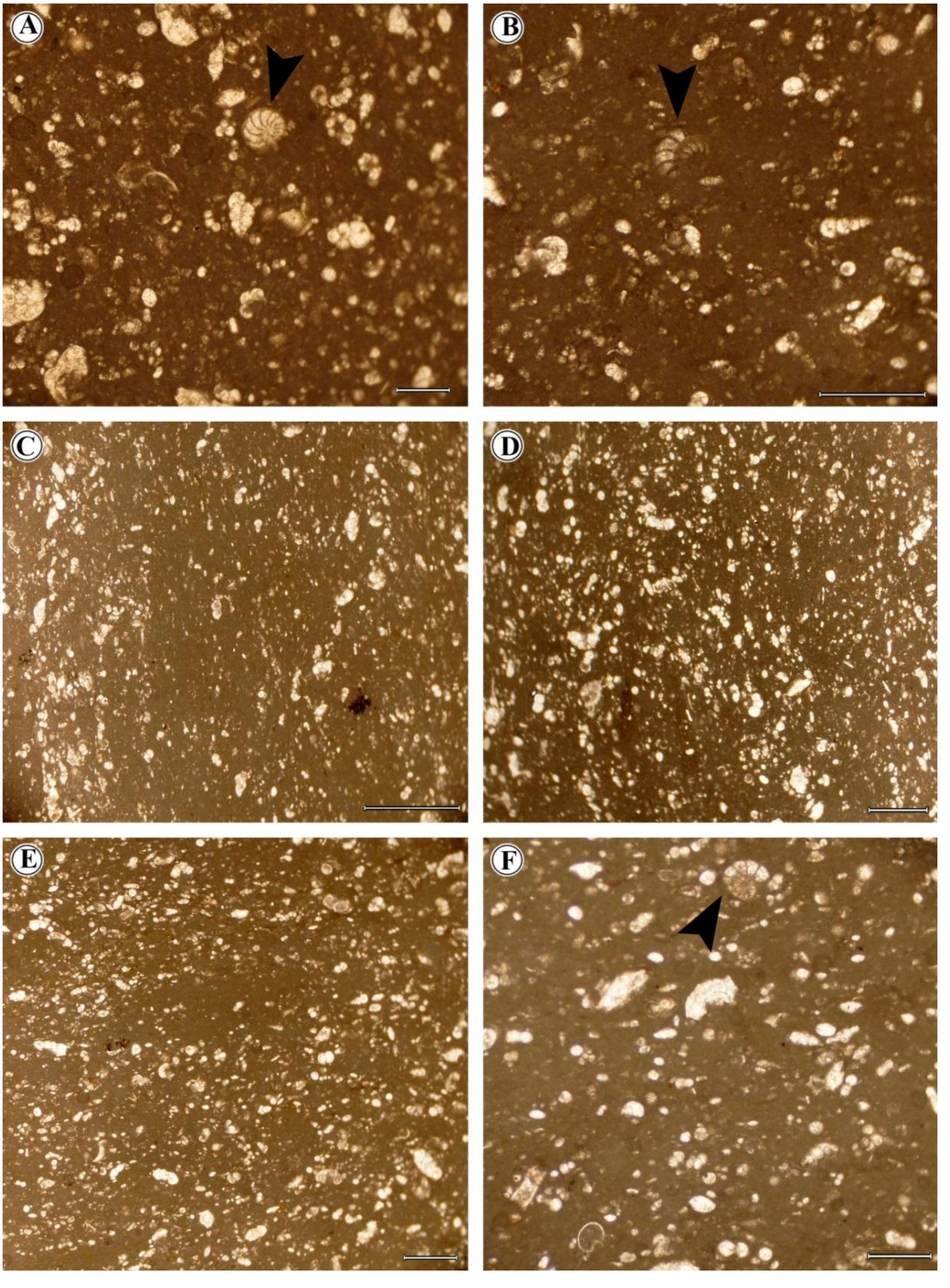

Fig-5. White arrows indicate dissolution under pressure (Stylolites). These thin sections were prepared from the weak samples, no. 3, 7 and 11. Scale bars equal 1 mm.

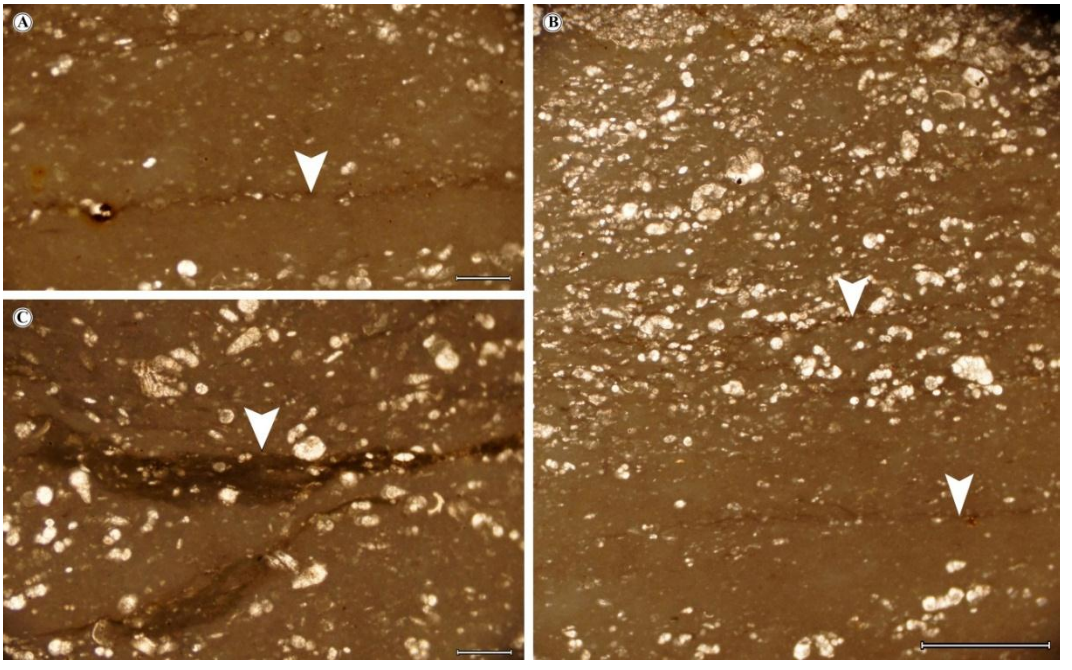

Table-1. Number of prepared specimens parallel and perpendicular to bedding of both cubes and prisms

Specimens No.	Cubes 100 x 100 x 100 mm		Prisms 100 x 100 x 200 mm	
	Parallel to bedding	Perpendicular to bedding	Parallel to bedding	Perpendicular to bedding
1--11	11			
12--21		10		
22--30			9	
31--41				11

Table-2. Results of unit weights, water absoption and compressive strength of cubes specimens

Specimen No.	Weight (kg)		Unit Weight (kg/m^3)		Water Absorption %	Compressive Strength (MPa) of 100 x100 x100 (mm) Cubes			
						Dry		Saturated	
	Dry	Saturated	Dry γ_{dry}	Saturated γ_{sat}		Load Parallel to Bedding	Load Perpendicular to Bedding	Load Parallel to Bedding	Load Perpendicular to Bedding
1	2.616	-	2616	-	-	82.06	-	-	-
2	2.496	-	2496	-	-	106.52	-	-	-
3	2.636	-	2636	-	-	55.90	-	-	-
4	2.578	-	2578	-	-	108.13	-	-	-

5	2.568	-	2568	-	-	104.10	-	-	-
6	2.602	2.686	2602	2686	3.23	-	-	76.63	-
7	2.674	2.74	2674	2740	2.5	-	-	39.98	-
8	2.534	2.604	2534	2604	2.76	-	-	94.43	-
9	2.646	2.734	2646	2734	3.33	-	-	88.02	-
10	2.5	2.576	2500	2576	3.04	-	-	75.13	-
11	2.552	2.628	2552	2628	3	-	-	35.12	-
12	2.516	-	2516	-	-	-	82.45	-	-
13	2.568	-	2568	-	-	-	102.08	-	-
14	2.594	-	2594	-	-	-	100.45	-	-
15	2.654	-	2654	-	-	-	105.47	-	-
16	2.564	-	2564	-	-	-	96.18	-	-
17	2.628	2.698	2628	2698	2.6	-	-	-	70.30
18	2.6	2.7	2600	2700	3.85	-	-	-	57.65
19	2.598	2.68	2598	2680	3.2	-	-	-	38.92
20	2.56	2.65	2560	2650	3.5	-	-	-	73.40
21	2.574	2.662	2574	2662	3.42	-	-	-	63.79

Table-3. Results of unit weights, water absoption and compressive strength of prisms specimens

Specimen No.	Weight (kg)		Unit Weight (kg/m^3)		Water Absorption %	Compressive Strength (MPa) of 100 x100 x200 (mm) Prisms			
						Dry		Saturated	
	Dry	Saturated	Dry γ_{dry}	Saturated γ_{sat}		Load Parallel to Bedding	Load Perpendicular to Bedding	Load Parallel to Bedding	Load Perpendicular to Bedding
22	5.006	-	2503	-	-	72.00	-	-	-
23	5.088	-	2544	-	-	57.20	-	-	-
24	4.978	-	2489	-	-	50.00	-	-	-
25	5.124	-	2562	-	-	98.35	-	-	-
26	5.058	-	2529	-	-	81.00	-	-	-
27	4.926	5.084	2463	2542	3.21	-	-	40.00	-
28	5.076	5.236	2538	2618	3.2	-	-	32.43	-
29	5.186	5.294	2593	2647	2.1	-	-	27.43	-
30	5.11	5.242	2555	2621	2.6	-	-	66.76	-
31	5.122	-	2561	-	-	-	70.00	-	-
32	5.068	-	2534	-	-	-	60.00	-	-
33	5.14	-	2570	-	-	-	50.00	-	-
34	5.176	-	2588	-	-	-	48.00	-	-
35	5.122	-	2561	-	-	-	56.60	-	-
36	5.03	5.204	2515	2602	3.5	-	-	-	35.72
37	5.1	5.274	2550	2637	3.4	-	-	-	19.33
38	5.012	5.168	2506	2584	3.11	-	-	-	42.28
39	5.065	5.23	2532.5	2615	3.3	-	-	-	53.65
40	5.02	5.158	2510	2579	2.45	-	-	-	41.88
41	5.062	5.238	2531	2619	3.5	-	-	-	43.20

Table-4. ASTM standard specifications for limestone dimension stone

Categories	Absoption %	Density kg/m^3	Compressive Strength Mpa	Test Method
Minimum	3.0%	1760-2160	12	C 97
Medium	7.5%	2160-2560	28	C 97
Maximum	12.0%	>2560	55	C 170

Table-5. Average of compressive strength of cubes and prisms specimens

Specimens	Average of Compressive Strength (Mpa)			
	Load Parallel to bedding		Load perpendicular to bedding	
	Dry	Saturated	Dry	Saturated
Prisms	71.72	46.4	56.92	43.35
Cubes	100.2	74.84	97.33	66.29

Table-6. Comparison between the compressive strength of cubes and prisms

Compressive Strength (MPa) 100 × 100 × 100 (mm) Cubes		Compressive Strength (MPa) 100 × 100 × 200 (mm) Prisms		Correction Factor Conversion from Prism to Cube (Multiple by) Conversion from Cube to Prism (divide by)	
Average Dry and Saturated		Average Dry and Saturated		Average Dry and Saturated	
Load parallel to bedding	Load perpendicular to bedding	Load parallel to bedding	Load perpendicular to bedding	Load parallel to bedding	Load perpendicular to bedding
87.52	81.81	59.06	50.14	1.48	1.63