Article

Influence of Petrographic Properties on the Strength and Durability of Dolomite and Limestone for Infrastructure Develoment

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Abstract

The paper presents the basic problem related with practical application of carbonate rocks in construction: are carbonate aggregates produced from such rocks favorable for building engineering, particularly for construction? (1) the geological-engineering properties of aggregates are presented, (2) the correlation between petrographic and engineering. This knowledge has allowed to assess the usefulness made from dolomite and limestone design and construction structures. petrography was characterized using optical microscopy and scanning electron microscopy (SEM) coupled with energy-dispersive X-ray spectroscope (EDS). Engineering properties were determined in accordance with European and Polish norms and guidelines. Statistical and design calculations were performed using dedicated software. The petrographic properties, and selected physical and mechanical parameters of the aggregates, were tested to show their influence on the unconfined compressive strength and unconfined tensile strength. Strong functional relationships between the unconfined compressive strength, unconfined tensile strength and water absorption, have been observed. The support the sustainable use of locally available limestone resources in Pakistan and provide guidance for material selection in pavements, foundations, and other structural applications. These findings have direct economic implications for building and infrastructure design and promote more efficient and rational use of regional rock resources in the construction industry

Keywords: dolomite; Limestone; Physical properties, Mechanical properties; petrographic

1. Introduction

Rock aggregates have been utilized in many constructions industries. The geology of rock can be used to improve the quality of the structure, life span, and even security of the civil structure like bridges, highways, passageways, and even dams. Mechanical and physical properties are the most significant factors which define the strength of rock [1]. Rock as the building materials has been widely studied in terms of its geomechanical behavior. Geomechanical properties of rocks are commonly compound effect of various other related factors such as petrology, mineralogy, texture and form, erosion, permeability as well as fractures [2]. When rocks are incorporated in the construction of buildings, they have a number of physical and mechanical requirements in the building industry. Its texture, petrological characteristics, geological structures, and surrounding conditions are the main determinants of the physical characteristics of rock [3]. petrographic properties influence the geotechnical behavior of building materials. In order to understand their behavior, we have to put into consideration the manner in which rocks respond to different petrographic features which are the grain size, the shape, the orientation and the fractures [4]. In the classifications of rocks, the above petrographic features are hardly considered. Their influence on the strength is also studied in the contemporary research [5].

The physical characteristics of rock are known as index properties or parameters that determine the composition of rock to enable its classification. Mechanical property known as strength is the parameters or properties which inform us of the strength and durability of rock under a given set of conditions such as humidity, temperature and the loading conditions [6]. Besides the natural physical and chemical properties of rocks, non-technical methods of excavating rocks applied in the construction industry also affect the rock strength. The characteristics of building material vary according to the type of rock and are greatly influenced by processes used to form rock besides the outside factors that occur throughout the entire metamorphism of the rock [7,8].

Moreover, a comparison of the suitability of these two formations in terms of potential advantages and constraints for building material applications is intended. For instance, although the limestone with high-quality calcite content may have higher strength and abrasion resistance ability, the dolomite may possess workability and cheaper value advantage [9]. Through these properties, the research might help engineers, architects and policy makers select consciously which limestone resources to exploit with regard to specific construction functions. Not only this work is important for the comprehension of material properties but also these find use in overall discussion on sustainability as well as resource rationalization that can be applied in construction industry of Pakistan [10]. By taking a microscopic view of these sediments, we target material efficiency and sustainable building for regional development through enhanced knowledge of local limestone resources.

It will also contribute to the sustainable development of the construction industry in the long run by identifying opportunities for utilizing local limestone resources optimally. If we focus on the prevalence of these formations, and look at local geological conditions (substrate, ground water and climate) as they are likely to have influenced modelled occurrences in limestone when it was used in the respective area as a building material [11]. This research objectives to contribute a model that to address the overall issues and development of composite model for selection best suited limestone resources through targeted goal in construction industry of Pakistan.

1.3 Main Aim of the Work

This paper will fill in this gap by giving a comprehensive correlation of geological knowledge and lithological and petrographic properties of the carbonate rocks, and their

88 engineering properties. The proposed study tries to fill this gap in understanding by es-
89 tablishing the ineffectiveness of the known relationship between geotechnical properties
90 of carbonate rocks and their resistance against environmental factors. This research aims
91 at achieving the following objectives:

92 This paper explores the relationship between geotechnical properties and environ-
93 mental resistance parameters, determining the prospect of using carbonate aggregates in
94 the construction. This study will also aid new economic and major infrastructural growth
95 throughout the area, particularly as such projects connect to the China–Pakistan Economic
96 Corridor (CPEC).

2. Geological Setting

2.1 Amber Formation – Dolomite

100 The study region (Figure.1) is the located of the Ambar Formation, situated in village
101 Anbar, District Swabi, Khyber Pakhtunkhwa, Pakistan. The area has fairly good road con-
102 nections with major towns through metallic and semi-metallic roads. The area of the study
103 is approachable through Peshawar, Nowshera and Islamabad via G.T. Road on Motorway
104 up to Swabi interchange. The distance from Islamabad is approximately 104 km, and from
105 Peshawar, it is 91km via the Motorway.

2.1 Inzari Formation – Limestone

107 The study area for the Inzari Formation (see Figure 1) is located in Tar Khel Village,
108 District Nowshera, Pakistan, where the typical Inzari Formation Limestone is present. The
109 coordinates for this area are: Latitude: 33°50′31.69″ Longitude: 72°09′10.48″ E. The area is
110 approximately 97 km from Peshawar and 135 km from Islamabad.
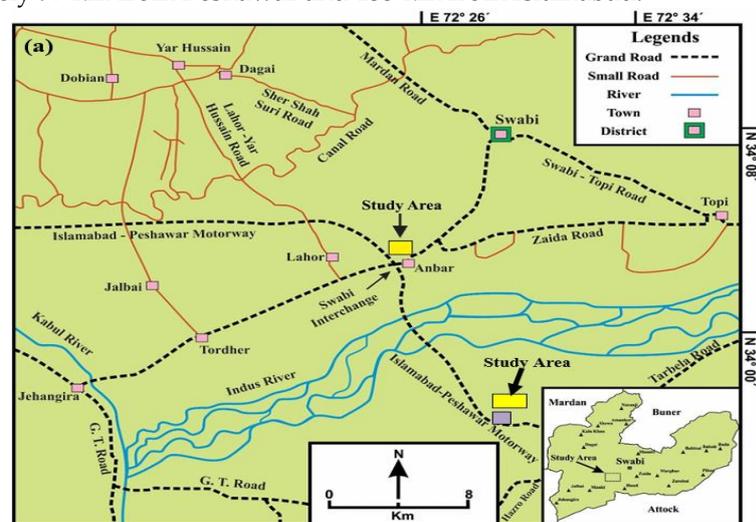

Figure 1. A map showing the research areas location in Pakistan

3. Materials and Methods

3.1. Materials

115 The studies were conducted on samples from two carbonate units in northern Paki-
116 stan: the Ambar Formation (dolomite) and the Inzari formation (Limestone), both widely
117 exposed cross the Peshawar Basin and the Attock–Cherat–Khattak–Nizampur region of
118 Khyber Pakhtunkhwa (Figure 1a). The Ambar Formation (Figure 2c, e,) is generally re-
119 garded as Cambrian in age and consists predominantly of dolomite and dolomitic lime-
120 stone, interbedded with quartzite and argillite.

The Inzari Limestone (Figure 2b, d,), named after Inzari village, occurs in the same regional belt and is characterized as a thin- to medium-bedded, yellow to greenish-grey limestone. Regional syntheses place this unit within the Late Proterozoic to possibly Lower Paleozoic succession, contrasting earlier interpretations that assigned it a Mesozoic (Jurassic) age.
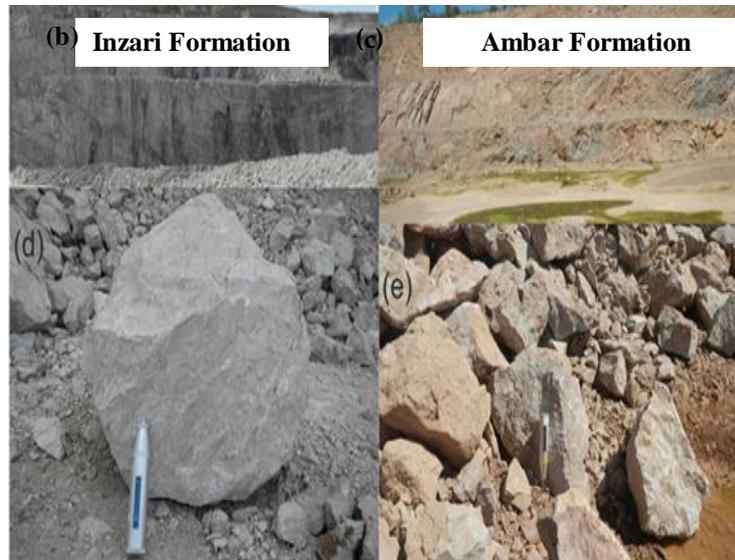
Figure 2. Ambar dolomite quarry and Inzari limestone quarry: (a) location and general view of Ambar and Inzari quarries; (b) exploitation wall in Inzari quarry; (c) exploitation wall in dolomite quarry; (d) stone blocks in Inzari quarry; (e) stone blocks in dolomite quarry.

3.2 Methods

3.2.1. Petrographic Analysis

The representative samples of the Dolomite Amber Formation and Limestone Inzari Formation were analyzed petrographically. The studies were on micro techniques by which the small rock fragments and aggregate particles may be closely examined. Selected samples from each formation were cut into thin sections and analysed under both optical microscopy (OM) and scanning electron microscopy (SEM). In addition, SEM was used to study the fresh fracture surfaces of the samples for additional textural and compositional details [12-13].

(i)Thin Section Preparation: Thin sections were cut with ordinary glass slides (24×46 mm). Thin sections between 4 and 6mm were cut from coarse rock pieces, mounted on a slide with resin, and ground down using successively finer powders until a final thickness of 0.05–0.06mm (50–60μm) was achieved for imaging under the SEM. The glossy surface was found to facilitate good quality microscopic and chemical examination without a coating.

(ii) Optical Microscopy: Microscopic observations were performed with Nikon Eclipse 100 and Nikon E600POL optical microscopes, both digital cameras used. Types of analysis were the determination of rock texture and structure (grain size distribution, pore geometry, grain shape, and rounding), mineral identity, diagenetic modification, matrix composition, relics or secondary mineralization. The observations were made at a magnification up to 50times.

(iii) Scanning Electron Microscopy (SEM): SEM images were taken on a (JSM-6380LA) scanning electron microscope in conjunction with an Energy Dispersive X-ray Spectroscopy system containing a Bruker GmbH X-Flash 8/10 detector. The setup was

156   installed at a branch of the BESSY II Synchrotron Radiation Source utilizing the Berlin
157   Electron Storage Ring, with a tungsten reflector alternating monochromator and four
158   multispectral mechanical Soller slits directly in front and behind the detector to im-
159   prove energy resolution to (126 eV at Mn Kα and 45 eV at C Kα. Imaging was per-
160   formed in backscatter electron mode with magnification from 50 x to 3500x.

161   **4. Results**

162   *4.1 Petrography*

163   *4.1.1. Dolomite (Ambar Formation)*

164   In hand specimens, the dolomites of the Ambar Formation range from light to dark
165   grey. Thin sections reveal predominantly fine-to medium-grained textures, composed
166   mostly of dolomite crystals (63–70.9%), with micrite (16.6–23.8%), sparite (2.2–6.8%),
167   quartz (0.8–10.9%), and opaque minerals (0.2–4.5%), as shown in in Figure.5a. Differ-
168   entiation between calcite and dolomite is difficult in hand specimens and thin sections
169   due to similar optical properties; therefore, calcite imparted a pink coloration, while
170   dolomite remained unstained [14].

171   *4.1.2 Limestone (Inzari Formation)*

172   The Inzari Formation Limestone, classified as a micritic mudstone is primarily com-
173   posed of 60% micrite, 15-16% sparite, 14-17% calcite, 9% quartz, and 30-40% opaque
174   minerals, as shown in Figure 5b. It exhibits early dolomitization, with rhombohedral
175   dolomite crystals forming in the matrix. The rocks are severely fractured due to re-
176   gional uplift during Pliocene N–S shortening in the Attock–Cherat Ranges. Fractures
177   are cross-cutting, often filled with calcite, manganese, or iron hydroxides [15].
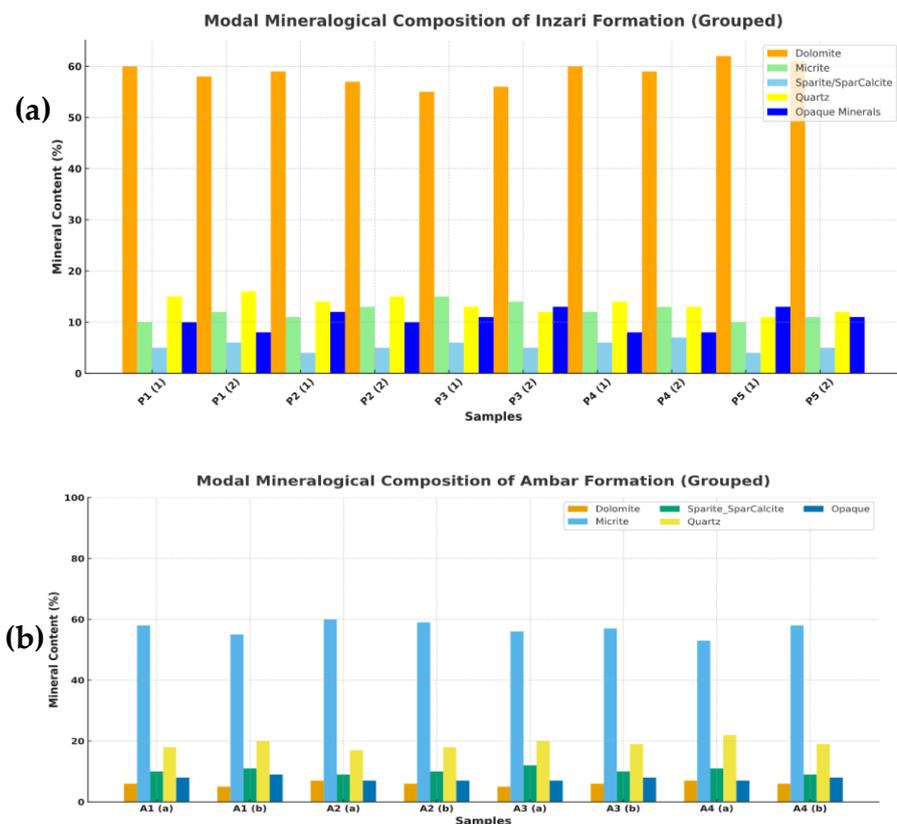

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180   **Figure 3**. Petrography, mineralogy, structure, and texture of dolomite and limestone aggregates:
181   a) Mineral composition of Inzari formation;(b) Mineral composition of amber formation

182 The SEM analysis was conducted to examine the micro-morphological characteristics
183 and chemical composition of the dolomite crystals [16]. This analysis provides insights
184 into the transformation processes of carbonate rocks over geological time.The rock
185 demonstrates numerous essential traits suggestive of these alteration processes, includ-
186 ing:

- Dolomitization happens within dolomite crystals, creating a lighter crust around them.
- The crust is dense, non-porous, and lacks the white patches commonly seen as remnants of the original limestone.
- The centers of the crystals are darker, with white areas and a porous structure.
- Intercrystallite pores, measuring between 20 to 30 microns, are infrequent, while smaller.
- intercrystallite pores ranging from 6 to 0.5 microns are more abundant in the crystal centers. These pores are not hydraulically connected.
- Several caves, both regular and irregular, contain secondary mineralization.
- Fractures are commonly present, with veins containing calcite mineralization.
- Lighter patches, remnants of limestone, appear within the darker dolomite matrix.

199 *4.2 Geotechnical Properties*

200 The statistically summarized analysis results are shown in Tables 1 and 2 and Figures
201 4-5. These analyses make a universal comparison of the major geotechnical properties be-
202 tween dolomite and limestone aggregates. The differences and similarities of the proper-
203 ties of these two types of aggregates were discussed in sections below with their respective
204 natures based on independent testing methods. Their comparative analysis is useful for
205 the evaluation of these aggregates for a wide range of geotechnical works and insights on
206 their behavior in specific conditions.

207 *4.2.1. Unconfined Compressive Strength (UCS)*

208 Results of unconfined compressive strength (UCS) tests for investigated dolomite
209 and limestone samples are summarized in Table 1, and presented at Fig.4a, b There is a
210 variation in the values of compressive strength. The mean compressive strength of dolo-
211 mite samples is 68.4 MPa and that of the limestone sample are 56.3 MPa. This may imply
212 that most dolomite samples are relatively stronger in terms of being resistant to crush
213 forces, and therefore can be considered more durable.

214 *4.2.2 Unconfined Tensile Strength (UTS)*

215 Based on unconfined tensile strength test results, the evaluated aggregates also have
216 different levels of compressive strength. Tensile strengths of dolomite aggregates are be-
217 tween 7.8 and 9.2 MPa (Table 1 and Figure 4c). The average compressive strength of do-
218 lomite was about 8.3 MPa. Opposing, for limestone aggregates the strengths are varied
219 between 4.44 and 9.51 MPa with an average value of 6.8 MPa (Table 1, Figure 4d). These
220 values also show a moderate tensile strength value as property of the aggregates, since
221 they are part of the concentrated data for both tables. It was concluded from these results
222 that dolomite aggregates are generally stronger in tension than limestone and as such may
223 be a suitable material where greater strength is required [17].

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4.2.3 Specific gravity Test

From specific gravity tests, the aggregates analyzed have different densities. The average value of specific gravity for Dolomite aggregate is 2.83 gm/cm³, and ranging from 2.81 to 2.86 (Table 1, Figure 4e). These values imply that the dolomite aggregates are of high density.

For Limestone aggregate, however the specific gravity values vary between 2.607-2.66 with a mean value of 2.644(Table 1, Figure-4f). The density of the limestone aggregate is less than the dolomite aggregate. Based on specific gravity (SG) aggregate classification, the dolomite and limestone aggregates fell under the medium density category.

4.2.4. Water Absorption test;

Dolomite aggregates have significantly lower water absorption than limestone. The water absorption for dolomite ranges from 0.03% to 0.22%, with an average of 0.09% (Table 1, Figure 4g), while limestone ranges from 0.10% to 0.37%, with an average of 0.23% (Table 1, Figure 4h).

This makes dolomite more water-resistant and a better choice for applications where moisture absorption is critical. Additionally, the lower water absorption of dolomite contributes to its overall durability in harsh environmental conditions.

4.2.5. Porosity Test

Porosity values of the dolomite aggregate samples range from 0.09% to 0.62% with an average of 0.36% (Table 1, Figure 4i). In terms of porosity, the content of that in limestone aggregate is between 0.55% and 0.97%, and the average value is 0.76% (Table 1 Figure 4j). It suggests that dolomite aggregates have a lower level of porosity in normal situation, thus being stronger and more durable for using in water-resistant fields. On the opposite side, higher porosity characterizes limestone aggregates and this could lead to freezing in presence of glaciers and being subject to water absorption phenomena under ambient conditions with consequent negative effects on properties.

4.2.6. Point load Test

The dolomite aggregates have an average dry weight ranging from 529.81g to 559.15g, with point load values between 2.81 and 2.86 (Table 1, Figure 4k), indicating strong and consistent load-bearing capacity. In contrast, the limestone aggregates have an average oven-dry weight ranging from 328.47 g to 346.92 g, with point load values between 0.57 and 0.96 (Table.1 Figure 4l). This indicates that dolomite has higher strength and more consistent properties compared to limestone in point load testing. Overall, dolomite aggregates demonstrate superior performance in strength and consistency.

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Table 1: Statistical Data for Physical and Mechanical Properties of Dolomite and Limestone Aggregates (Min: Minimum Value, Max: Maximum Value, Mean: Average Value, SD: Standard Deviation)

Parameter	Average	Dolomite	Limestone
Unconfined Compressive Strength (UCS) test	min	25	30
	mix	140	80
	mean	2.82	56.3
	sd	28.7	12.5
Unconfined Tensile Strength (UTS) Test	min	7.81	4.44
	mix	9.22	9.51
	mean	8.52	6.81
	sd	0.40	1.464
Specific gravity test	min	2.81	2.607
	mix	2.86	2.66
	mean	2.83	2.64
	sd	0.01	0.01
Water absorption Test	min	0.03	**0.10**
	mix	0.22	0.37
	mean	0.12	0.23
	sd	0.05	0.07
Porosity Test	min	0.09	0.55
	mix	0.62	**0.97**
	mean	0.36	0.76
	sd	0.15	0.12
Point Load Test	min	**2.81**	0.57
	mix	2.86	0.96
	mean	2.83	0.76
	sd	0.01	0.11

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Dolomite Aggregate   **Limestone Aggregate**

(a)   **(b)**

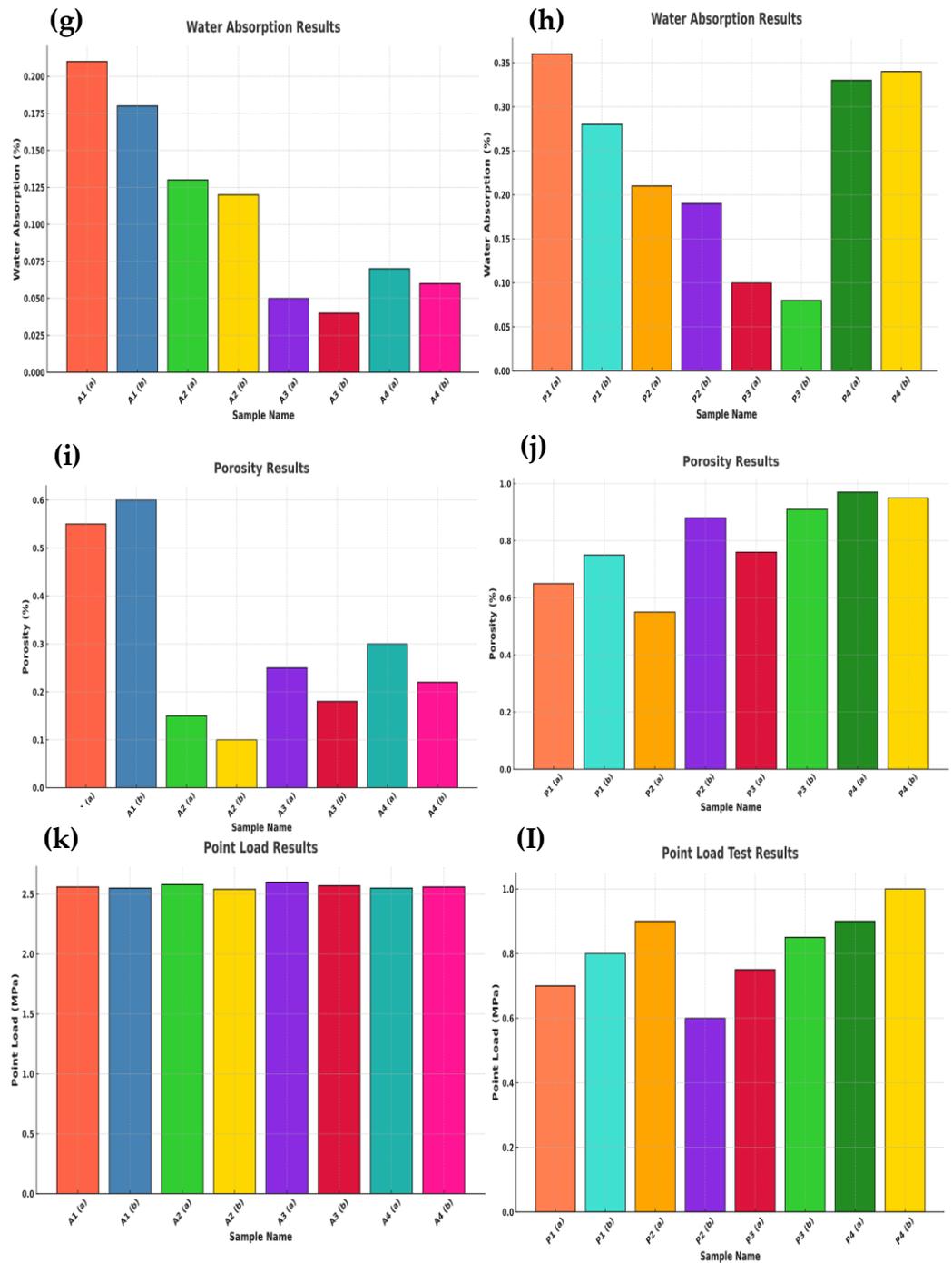**(c)**   **(d)**


(e)   **(f)**
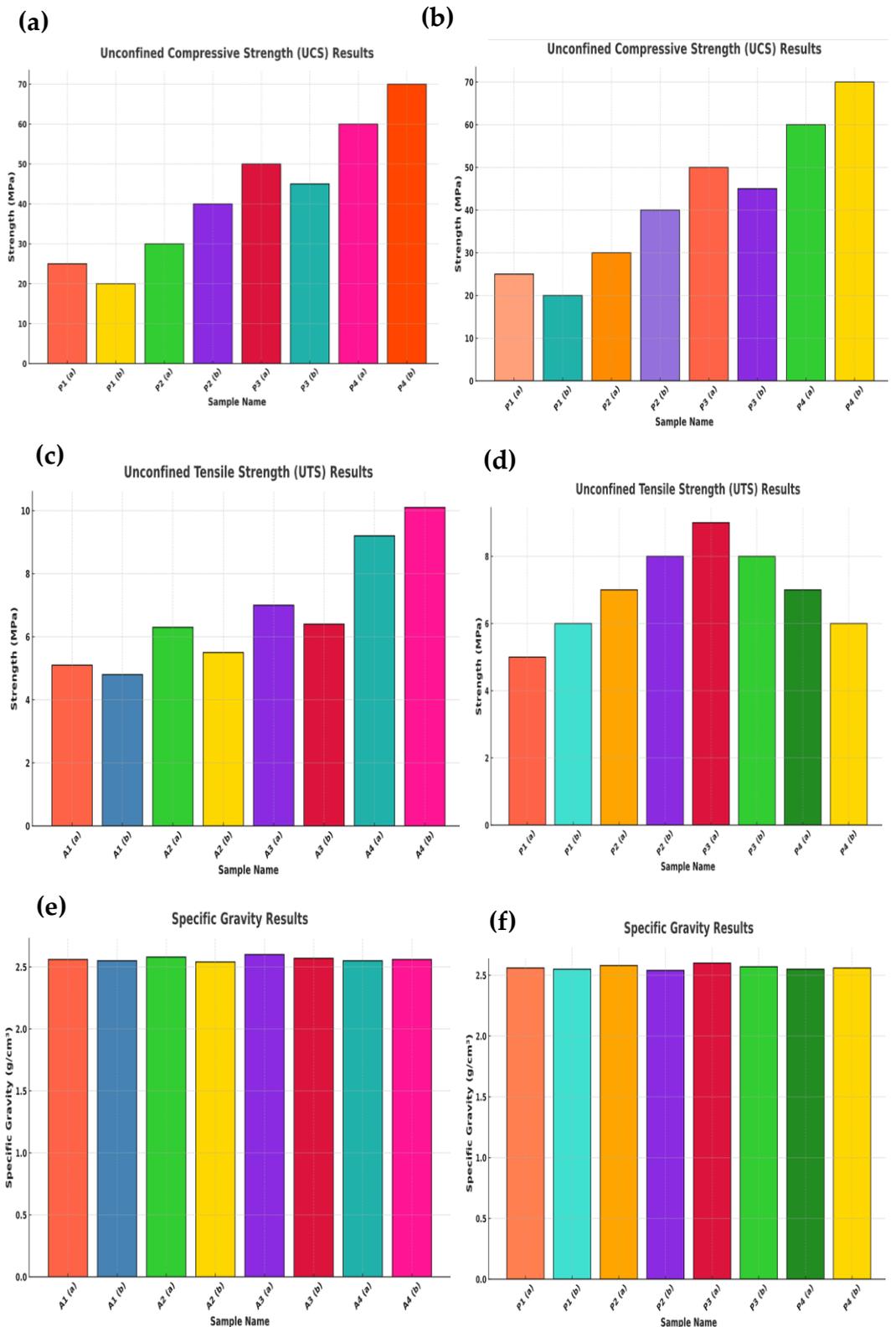
Figure 4. Distribution histograms of geotechnical parameters for carbonate aggregates.

4.3 Relationships between dolomite and Limestone

The correlation coefficients between the mechanical and physical characteristics of dolomite and limestone aggregates are shown in Table 2. The data shows that limestone aggregates generally exhibit higher correlation coefficients than dolomite aggregates [18]. The correlation coefficients for both kinds considerably increased when the aggregates' properties were averaged. For dolomite, the relationship between Unconfined Compressive Strength (UCS) and Unconfined Tensile Strength (UTS) shows nearly full correlation, indicating that bulk density plays a significant role. However, other relationships exhibit poor or average correlations. In difference, limestone aggregates show high or near-perfect correlation coefficients across most parameters.

The correlations between various mechanical and physical characteristics of dolomite and limestone aggregates are shown in Figure 5. The results show a strong correlation between UCS and UTS for both dolomite ($R^2 = 0.88$) and limestone ($R^2 = 0.89$). The specific gravity and water absorption relationship is moderate for dolomite ($R^2 = 0.64$) and relatively strong for limestone ($R^2 = 0.77$). The porosity and point load test exhibit a weaker correlation for dolomite ($R^2 = 0.42$) but a strong one for limestone ($R^2 = 0.84$).
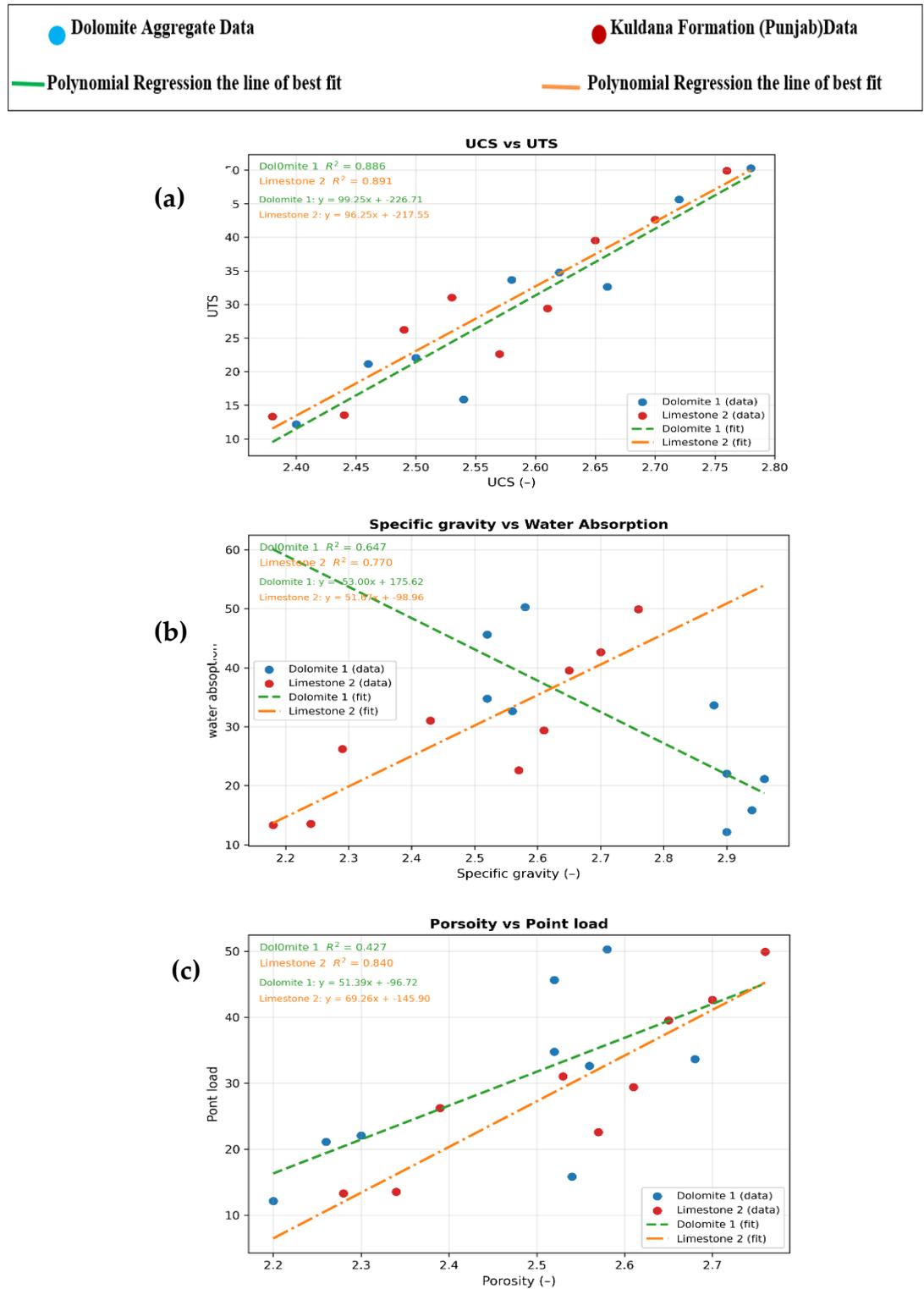
Figure.5 Relationships between geotechnical parameters for carbonate aggregates: (a) correlation between UCS and UTS; (b) correlation between Specific gravity and water absorption; (c) correlation between porosity test and point load test

Table.2. The correlation coefficient for different relationships is represented as follows: R1 represents the experimental data before averaging, fitted with a linear function, R2 represents the data after averaging, fitted with the best-fit function

	Correlation Coefficient			
Correlations	Dolomite		Limestone	
	R1	R2	R1	R2
UCS/UTS	68.4	0.88	56.3	0.89
Specific gravity/water absorption	2.83	0.64	0.23	0.77
Porosity test/Point load test	0.36	0.42	0.96	0.84

6. Conclusion

The findings of carbonate aggregate experiments show that lithology and petrographic characteristics play an important role in defining the physical and mechanical performance of these materials. The findings underline the complexity of assessing natural aggregates and the need for a comprehensive interpretative approach. Proper aggregate selection is essential, as it directly influences the strength, durability, and long-term performance pavements and structural elements exposed to variable environmental conditions and intensive mechanical loading. The evaluation of dolomite aggregates from the Ambar quarry and limestone aggregates from the Inzari quarry has enabled the formulation of the following key conclusions.

1. Ambar dolomite is characterized as dolomitic packstone with dense, fine-grained textures, while Inzari limestone is mainly micritic mudstone with higher fracture-related porosity. These petrographic differences strongly affect durability and performance.

2. Dolomite exhibits higher unconfined compressive strength (68.4 MPa average) and tensile strength (8.3 MPa average) compared with limestone (56.3 MPa and 6.8 MPa, respectively), confirming its superior mechanical resistance.

3. Dolomite shows lower porosity (0.36%) and water absorption (0.09%) than limestone (0.76% and 0.23%), suggesting better resistance to moisture and long-term degradation.

4. Statistical analyses revealed strong relationships among UCS, UTS, density, and water absorption. Dolomite generally displayed stronger inter-parameter correlations, reflecting more consistent material behavior.

6. Patents

Author Contributions: H.A contributed to the conceptualization, methodology, and writing of the original draft. **J.X** contributed to the data analysis and interpretation, and reviewed the manuscript. **M.U.A** contributed to the petrographic analysis **A.D** provided support in writing the final manuscript. **A.N** crovided support in writing the final manuscript

Conflicts of Interest: The authors declare no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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