Open Journal of Civil Engineering, 2022, 12, 169-188
https://www.scirp.org/journal/ojce
ISSN Online: 2164-3172
ISSN Print: 2164-3164

Physio-Mechanical Properties and Petrographic Analysis of NikanaiGhar Limestone KPK, Pakistan

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How to cite this paper: Shah, S.Y.A., Bin, D., Obaidullah, Hussain, J., Hussain, K., Asghar, A., Hussain, H. and Rahman, A.U. (2022) Physio-Mechanical Properties and Petrographic Analysis of NikanaiGhar Limestone KPK, Pakistan. *Open Journal of Civil Engineering*, **12**, 169-188.
https://doi.org/10.4236/ojce.2022.122011

Received: March 19, 2022
Accepted: May 21, 2022
Published: May 24, 2022

Abstract

Petrographic, physical, and mechanical assessment investigation of NikanaiGhar limestone aggregate exposed in the Lower Dir area of Malakand Division, Pakistan, were conducted to evaluate and investigate its potential for use as a construction material for engineering projects. Different geotechnical tests and petrographic analyses were performed to evaluate its potential for construction purposes. Geotechnical tests include unconfined compressive strength, ultimate tensile strength test, specific gravity, share strength, porosity, and water absorption. The evaluated physical attributes were compared to standard specifications to determine their suitability as a construction material. Petrographic investigation indicates mainly two types of stones. Stylolitic spar stone and Spar stone are metamorphosed equivalent limestones and are not prone to alkali-silica reactivity. Mutual relationships between physical parameters have been described by simple regression analysis. Significant direct correlation of specific gravity with ultimate tensile strength and uniaxial compressive strength was noted. However, negative trends of Porosity with ultimate tensile strength and uniaxial compressive strength were observed which is in accordance with standard. The analysis revealed that the limestones of NikanaiGhar Formation fall within the standard specification limits and can be used as aggregates for the indigenous construction industry.

Keywords

Potential Aggregates, Geotechnical Study, Petrographic Analysis, Regression

Analysis, NikanaiGhar Limestone

1. Introduction

Globally, aggregates are mainly composed of natural or broken crushed rock materials, which are the major constituent of concrete and mainly cover 70% - 80% of its volume in construction. Crushed rock materials mainly comprise limestone, which is a sedimentary rock composed of calcium carbonate. In Sedimentary rock, primarily limestone is utilized in the aggregate industry, gravels, pebbles, cobbles, and crushed rocks are sedimentary rocks that constitute the majority of construction materials. However, depending on suitability and transportation costs, igneous and metamorphic rocks can also be utilized as construction materials [1]. Aggregates are formed from igneous rocks (such as granite, basalt, diabase, gabbro, andesite, pumice, and so on), metamorphic rocks (such as slate, marble, quartz, and so on), and sedimentary rocks (calcium carbonate) [2]. Marble is a metamorphic rock derived from crystalline limestone calcium carbonate-rich source material. Marbles are the metamorphosed equivalents of originally sedimentary carbonate rocks changed by contact and regional metamorphism [3]. Marbles are metamorphosed equivalents of sedimentary carbonate rocks that have been altered by contact and regional metamorphism. Metamorphosed carbonate rock could be calcitic or dolomitic depending on its original composition, the impurities may occur due to various calc-silicates and other minerals [4]. The metamorphism results in the recrystallization of calcium carbonate at elevated temperatures and pressures [5].

Rock aggregates are essential construction resources for roads, highways, buildings, railway lines, water canals, and other small and large civil projects [6]. Rock aggregates make up over 90% of asphalt pavements and 80% of concrete used in building and road construction, respectively [6] [7]. The crushed materials (rock fragments) used for aggregates must have the ability to withstand limitations that are in the form of abrasion, crushing, impacting, and disintegrations when they are stored and processed on an asphalt pavement compacted with rollers and exposed to loading [6]. Attrition of asperities, corner breaking, and splitting particles into two or more parts are the most common types of aggregate degradation [8]. Therefore, geological studies are conducted when an aggregate supply is required to evaluate the location, distribution, and character of probable aggregate sources in the area [9].

To improve the strength of aggregate in any civil construction, it is necessary to establish the mineralogical composition, chemical, and physical properties of the rock material [10] [11]. Physical properties of an aggregate include texture, grain size, absorption, specific gravity, abrasion, impact value, crushing value, shape, etc. Chemical properties represent the chemical composition of aggregate, which is most important to assure aggregate suitability in a conditional environment. Before being used as a construction material, an aggregate must fulfill a standard specification, mainly recommended by the United Kingdom or the United States [7].

Pakistan has a variety of aggregate resources for construction, with limestone being one of the most important natural aggregate supplies for the construction sector [12]. With an enormous increase in demand for construction materials due to China-Pakistan Economic Corridor (CPEC) and other mega and minor projects in Pakistan, it is imperative to carry out prospective research to explore new resources. A variety of Limestone rocks with varied color, mineralogy, textural characteristics, and mechanical properties are exposed in different parts used as construction material in Pakistan.

The present study is conducted in Lower Dir, Malakand division (**Figure 1**). This research evaluates the NikanaiGhar Formation (Limestone) for the feasibility of potential aggregate. The geotechnical, petrographic, and physiochemical investigations can be used to determine the appropriateness of aggregates for construction works. To the author's knowledge, no research on the physical/mechanical and petrographic properties of NikanaiGhar Formation for road

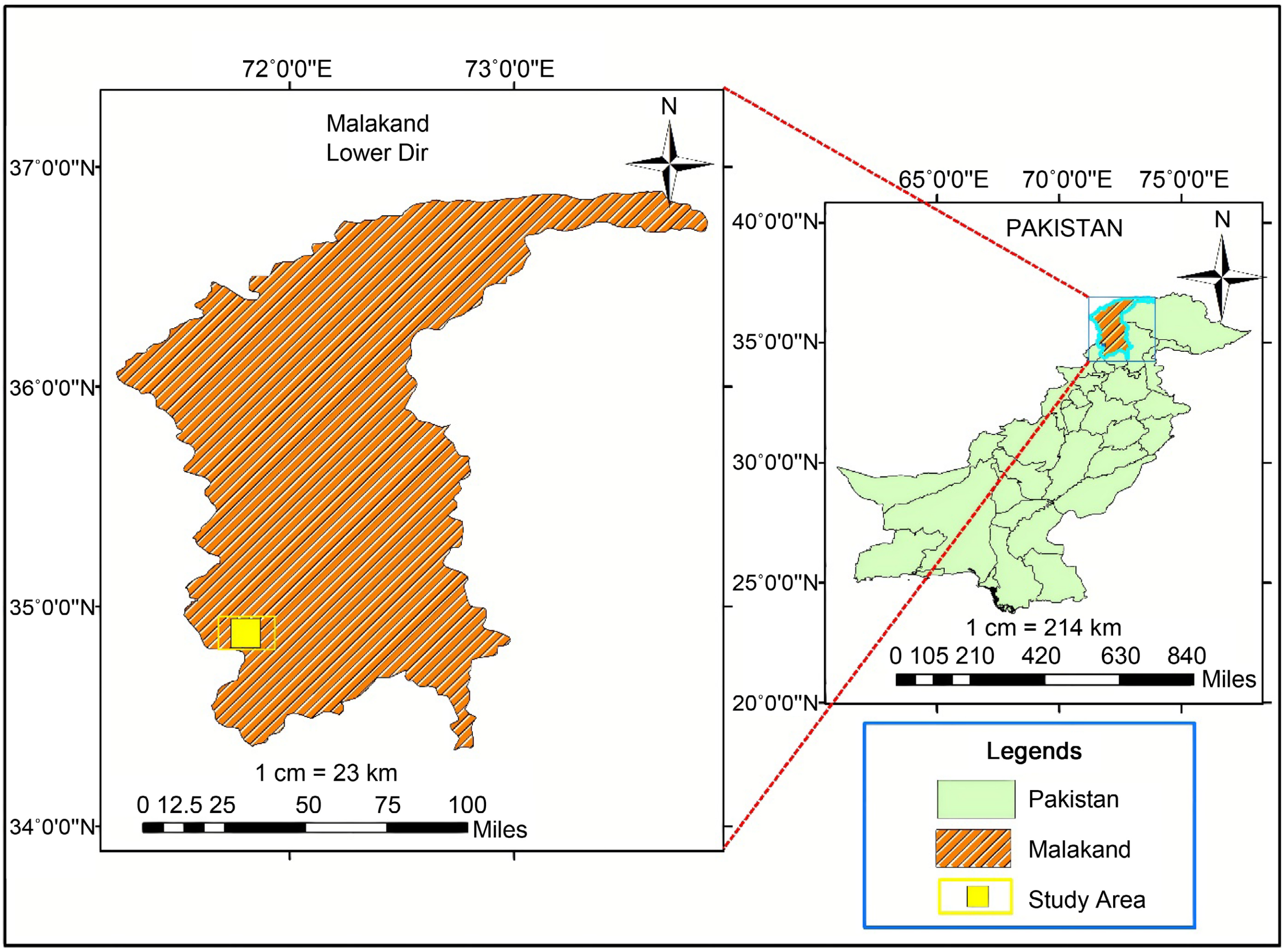

Figure 1. Locality map of the study area.

and concrete work has been conducted. The current research assessment is built on petrographic analysis, Geotechnical/Geological testing, focusing to evaluate the NikanaiGhar Formation for construction purposes.

2. Study Area

The present study area geologically lies on the northern tip of Indian plate where Precambrian to Mesozoic argillites, quartzite and limestone record a history of shelf deposition interrupted by numerous erosional unconformities [13].

Locality

A huge outcrop of limestone and marbleized limestone present at longitude N 34˚39'43.08" and latitude is E 072˚01'46.95" at 400 m south of Chakdara bazar, on the right side of GT road Chakdara district Lower Dir, Malakand division, Khyber Pakhtunkhwa, North Pakistan. The study area is accessible through main GT road Chakdara (**Figure 1**). The study area is present in Chakdara which is located in the foothills of the Himalayan Mountains at an altitude of 400 m.

3. Geologic and Stratigraphic Setting of the Study Area

3.1. Geological Setting

The present geologically lies on the northern tip of Indian plate where Precambrian to Mesozoic argillites, quartzite and limestone record a history of shelf deposition interrupted by numerous erosional unconformities [14]. The study area is a part of Alpurai group which is further sub-divided by [15] into four formations *i.e.*, Marghazar, Kashala, Saidu and NikanaiGhar (**Figure 2**) [16]. NikanaiGhar marble refers to massive marble and dolomitic marble exposed on NikanaiGhar Mountain in southern Swat [16]. These rocks constitute the upper one-third of rock sequence formerly known as the calcareous schist of the lower Swat-Buner schistose group and marbles [13]. The NikanaiGhar is the youngest meta-sedimentary unit which is exposed in southern Swat. Minor lithology includes calcareous quartzite, schistose marble, thin beds of calcareous schist.

3.2. Stratigraphic Setting

Alpurai Group

Alpurai group is divisible to four formations [17] (**Figure 3**). The lower part of this group consists of pelites, psammites and amphibolites while the upper part contains marble, graphite and garnetiferous calc-pelite [18].

1) Marghazar formation:

It takes its name from Marghazar village 6 km south of Saidu where the formation lies to the north and south of the Marghazar village [19]. The formation contains garnetiferrous muscovite schist, dark grey-weathered phlogopite marble, amphibolite schist, epidote biotite schist, psammitic schist, calcite marble,

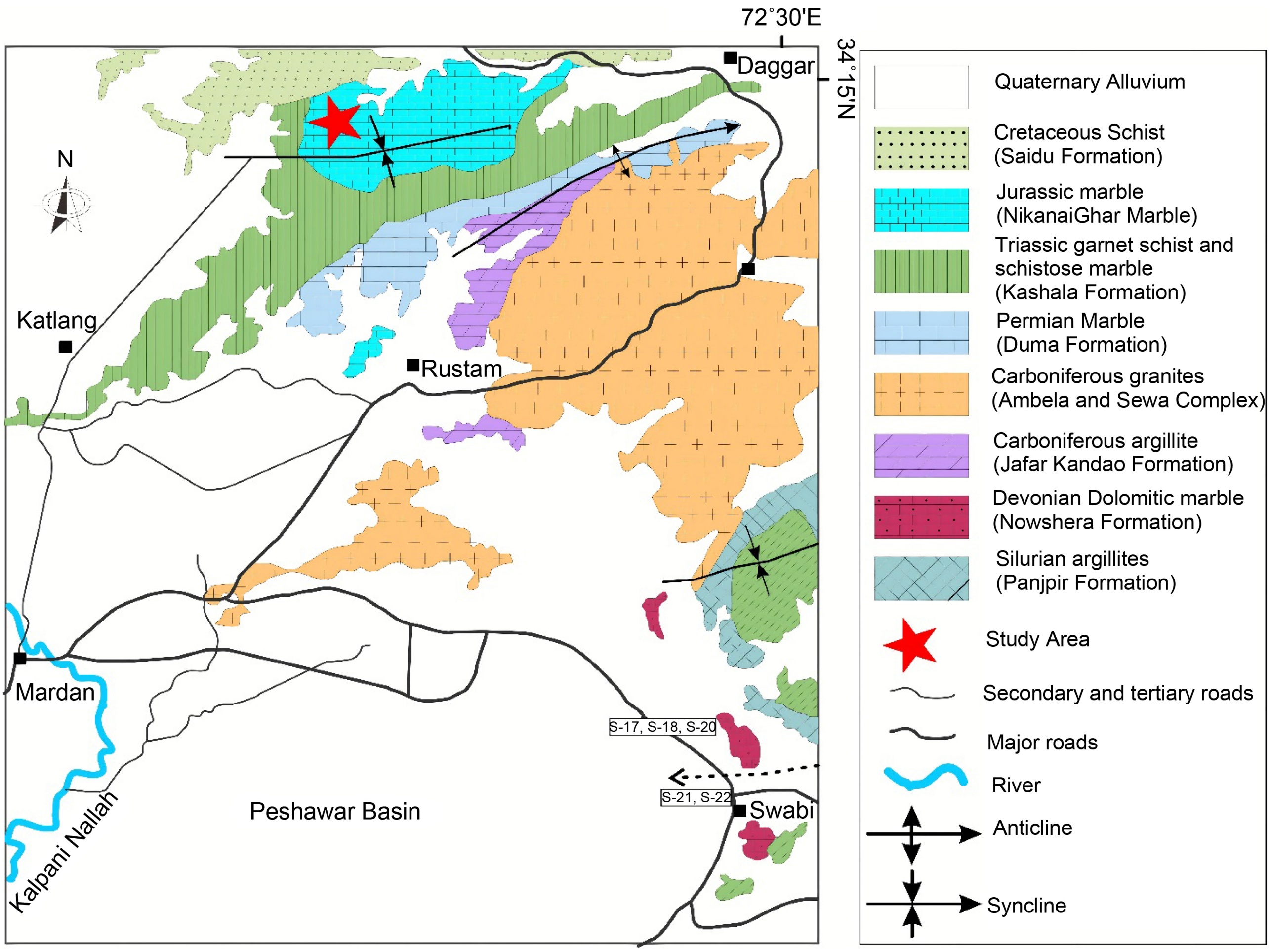

Figure 2. Geological map of the study area (modified) after A. Hussain.

feldspathic quartzite, amphibolites and rare graphitic schist [19].

2) Kashala formation:

The Kashala formation contains amphibolites which overlies at the top of the Marghazar formation. The Kashala formation consists of over 100 m thick dolomitic marble brown-weathering marble. The age of the formation is Late Triassic. The lower contact of the formation is not clear. It may be conformable, faulted or greatly sheared unconformity with Chakdara granite. The upper contact is gradational with graphitic schist of the Saidu formation [20].

3) NikanaiGhar formation:

[21] and [22] give the name as NikanaiGhar Marble based on dolomitic marble and massive marble lithologies. This formation is mainly composed of fine to coarse, white to dark-grey, thick-bedded to massive marble and dolomitic marble. Minor amount of schistose marble, calcareous schist and calcareous quartzite are also present.

4) Saidu formation

The Saidu Schist formation name is given by [23]. The Saidu formation is located to the north of Saidu along with the road cuts east of Mingora [24]. The

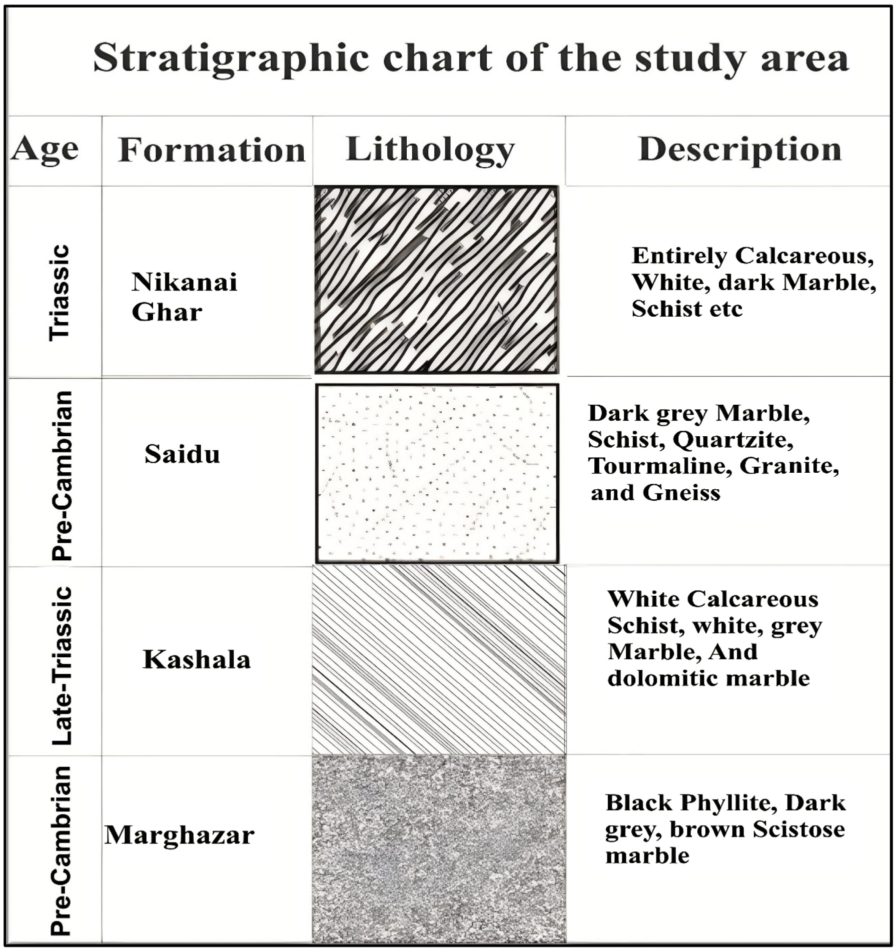

Figure 3. Stratigraphic map of the study area.

upper contact of this schist is marked by Main Mantle Thrust (MMT) in Saidu area. Fine to medium-grained, grey to dark grey pelites with minor amount of calcareous schist and marble are present near Saidu region. These rocks are folded and faulted. The graphitic phyllite is present in the crests of these folds. Based on mineral occurrence, these rocks are placed in the lower greenschist facies.

4. Methodology

4.1. Field Work

Detailed fieldwork was conducted in the area for the collection of samples and observation of outcrop features. Two bulks samples and crushed aggregate samples were collected for geotechnical and petrographic properties analysis. The location of the collected samples was marked with the help of GPS.

4.2. Laboratory Work

Two rock bulk samples collected during fieldwork were transferred to lab for geotechnical and petrographic analysis. The cores of the samples were prepared as per ASTM specification. With the help of core drilling machine, five cores were drilled from each bulk sample. Two chip samples were obtained for thin section preparation. Selected samples were tested for their engineering properties such as compressive strength, tensile strength, specific gravity, and water absorption.

4.3. Rock Strength

Rock strength is experimentally determined in the laboratory by testing undamaged and undisturbed sample, therefore, laboratory tests are more accurate and give satisfactory results than field tests. Different kinds of strength tests and physical tests were performed on samples in the laboratory are the following.

1) Uniaxial or Unconfined Compressive Strength (UCS) ASTM D-2938.
2) Uniaxial or Unconfined Tensile Strength (UTS) ASTM D-3967.
3) Shear Strength.
4) Specific Gravity.
5) Water Absorption.
6) Porosity.

4.3.1. Uniaxial or Unconfined Compressive Strength (UCS)

The maximum compression strength at which rock loses its strength is known as Uniaxial compressive strength. The standard method for UCS follows ASTM D-2938 specifications [25]. To tolerate homogeneous load the cores were cut and polished by rock cutting machine. The sample is then kept in universal compression machine and a uniform load was applied without any shock (**Figure 4**). The UCS can be find out by the following formula

$$\text{UCS} = P/A. \tag{1}$$

where P: Load and A = Cross sectional area of the core.

The calculated values were then compared with international standards classification for UCS (**Table 1**) [26].

Figure 4. Loading of core sample for compressive test UCS.

Table 1. Standard classification table of UCS after [26].

S. No.	Rock classification	Strength (MPa)
1	Very weak	<1.25
2	Weak	1.25 - 5.00
3	Moderately weak	5.00 - 12.50
4	Moderately strong	12.50 - 50
5	Strong	50 - 100

4.3.2. Unconfined Tensile Strength (UTS)

UTS is performed to measure the tensile strength by applying a vertical load to develop tension across the diameter of a rock disc being subjected to compression. The compressive strength of rocks is much higher than their tensile strength [27]. The direct measurement of tensile strength has frequently proven challenging due to the difficulty of gripping the specimen without generating bending stress [27]. Therefore, the splitting tensile test also named Brazilian test seems to be a desirable option as it is much simpler and inexpensive (ASTM-D3976) [28]. As per requirement, a disc-shaped specimen with thickness to diameter ratio of approximately 0.5 was selected from the core (**Figure 5**). The load at the time of failure of the specimen was noted. The following formula is used to obtain UTS.

$$\text{UTS} = \frac{2P}{\pi DT} \tag{2}$$

here:

P = Load (lbs.).

D = diameter of the rock core (in).

T = thickness of the rock core (in).

4.3.3. Shear Strength

A rock's shear strength is its maximum resistance to deformation caused by continuous shear displacement under the action of a shear [29]. Shear strength of the rock specimen is usually measured with torsion test in the laboratory Torsion tests are commonly used in laboratories to determine the shear strength of a rock specimen. Shear strength was not measured directly in the present research; rather, it was determined indirectly using the values of UCS and UTS [29]. According to scale, the UCS reading for the specific rock type was taken on the positive x-axis and the UTS reading for the same rock was taken on the negative x-axis. Mohr circles were drawn separately for the UCS and UTS measurements. A common tangent was drawn between the two resultant Mohr circles. Cohesion (C) and angle of internal friction (Φ) are the two factors used to calculate shear strength.

4.3.4. Porosity

Porosity means the presence of pore spaces in a rock. The agent that determines a rock's porosity is grain size, grain shape, and mineralogical composition, particularly the presence of clay minerals [27]. There exists an inverse relation between porosity and rock strength. To calculate porosity of the rock samples under investigation, saturation process was used demonstrated by [30]. Initially the dry weights of the samples were determined in open air and then suspended in water with the help of thread and calculated volume in water. The porosity is calculated by using the following formula. The International Standard Values for porosity are given in (**Table 2**).

$$P = \frac{(\text{wt. in air}) - (\text{dry wt.})}{(\text{wt. in air}) - (\text{wt. in water})} \times 100 . \tag{3}$$

4.3.5. Specific Gravity

It is the ratio of weight of a sample in air to its weight in water. The values of the specific gravity interpret about the strength and rock quality. The greater obtained values show higher strength, whereas smaller values show weaker strength or low quality of a rock. According to [31], rocks with specific gravity higher than 2.55 are suitable for construction. The test was performed according

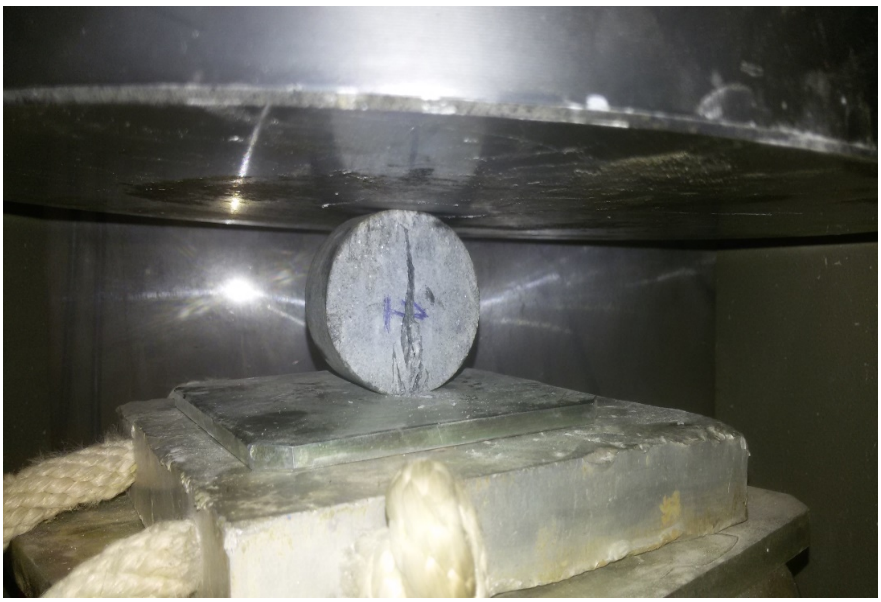

Figure 5. Loading of core sample for tensile test (UTS).

Table 2. Standard values of porosity and dry density after [32].

S. No.	Dry Density	Description	Porosity	Description
1	<1.8	Very low	Over 30	Very high
2	1.8 - 2.2	Low	30 - 15	High
3	2.2 - 2.55	Moderate	15 - 5	Medium
4	2.55 - 2.75	High	5 - 1	Low
5	Over 2.75	Very high	<1	Very low

to the ASTM C 127-12 [29]. The standard value of specific gravity for a rock is ≥2. To find out specific gravity Beaker, distilled water, digital weight balance and thread were used. Initially the samples were weighed and then placed in an oven for 24 hours at 105-110C temperature and is weighed again [33]. The samples were then kept in water and calculated their total volume specific gravity is find out by using the following formula

$$\text{Specific gravity} = \frac{W1}{W1 - W2}. \quad (4)$$

where, $W1$ = weight in air.

$W2$ = weight in water.

4.3.6. Water Absorption

Water absorption is the ability of rock to absorb water. According to [27] water absorption is an important factor in determining the hydration and dehydration effect, which will lead to the mechanical degradation of rock mass in contact with water, so as to make water enter, thus increasing the rate and degree of weathering. The quantity of water that an aggregate can absorb tends to affect its strength [34] [35] and [36] ASTM C127, state that aggregate water absorption values should be less than 1.5 and 2.5 percent, respectively. The water absorption test was conducted in the laboratory by passing through the following procedure.

The specimen under investigation was kept in oven for 24 hours at a temperature 105˚C - 110˚C and dried completely and weighed as $W1$ on sensitive electronic balance. The sample was then kept in distilled water for 24 hours and weighed as $W2$.

Water absorption is given by the following formula.

$$\text{water absorption } \% = \frac{W2 - W1}{W1} \times 100. \quad (5)$$

where, $W1$ = Dry weight.

$W2$ = Air weight.

4.4. Petrographic Analysis

Petrographic study shows textural context and model mineralogy of a rock based on thin section study [10]. This research includes both field observations and microscopic examination of thin sections. Understanding the origins of rock requires thin section analysis.

The study area consists mostly of meta-sedimentary rocks of Alpurai group.

During field work two bulk samples (S1 and S2) were collected for petrographic and physio-mechanical investigation. From each bulk sample two thin sections were prepared. The thin sections were studied under the cross and plane polarized light to examine the modal mineralogy and textural features. The texture is studied in detailed where various parameters are noted like grain size, geometry, cleavages, twinning, stylolites, grains contacts, cement, and matrix.

The rock is classified according to the [37] classification of Limestone. The rock is classified under the diagenetic category because due to the intense diagenetic process all the biological and depositional fabrics were destroyed. Wright (1992) classifies the carbonate into three main categories *i.e.*, depositional, biological, and diagenetic. These categories are further classified into sub-classes (**Figure 6**).

5. Results and Discussion

5.1. Physio-Mechanical Properties

The measured average calculated values for all physical and mechanical properties such as Specific gravity, Porosity, Water Absorption, Uniaxial Compressive strength, Tensile strength of sample SA1 and SB2 respectively, both fall in the limits of international Standards of road and concrete aggregate.

The specific gravity of the limestones ranges from 2.71 to 2.713, whereas that of marbleized limestone ranges from 2.81 to 2.64 (**Table 3**), with a minimum requirement of 2.60 for cement concrete. This implies that the specific gravity values of these rocks are within the limits of ASTM C127 [36]. The average calculated value of water absorption for limestone is 0.374% while for marbleized limestone is 0.634% (**Table 3**). According to the ASTM-C127 standard [36], the absorption capabilities of both analyzed rock types are well within the acceptable

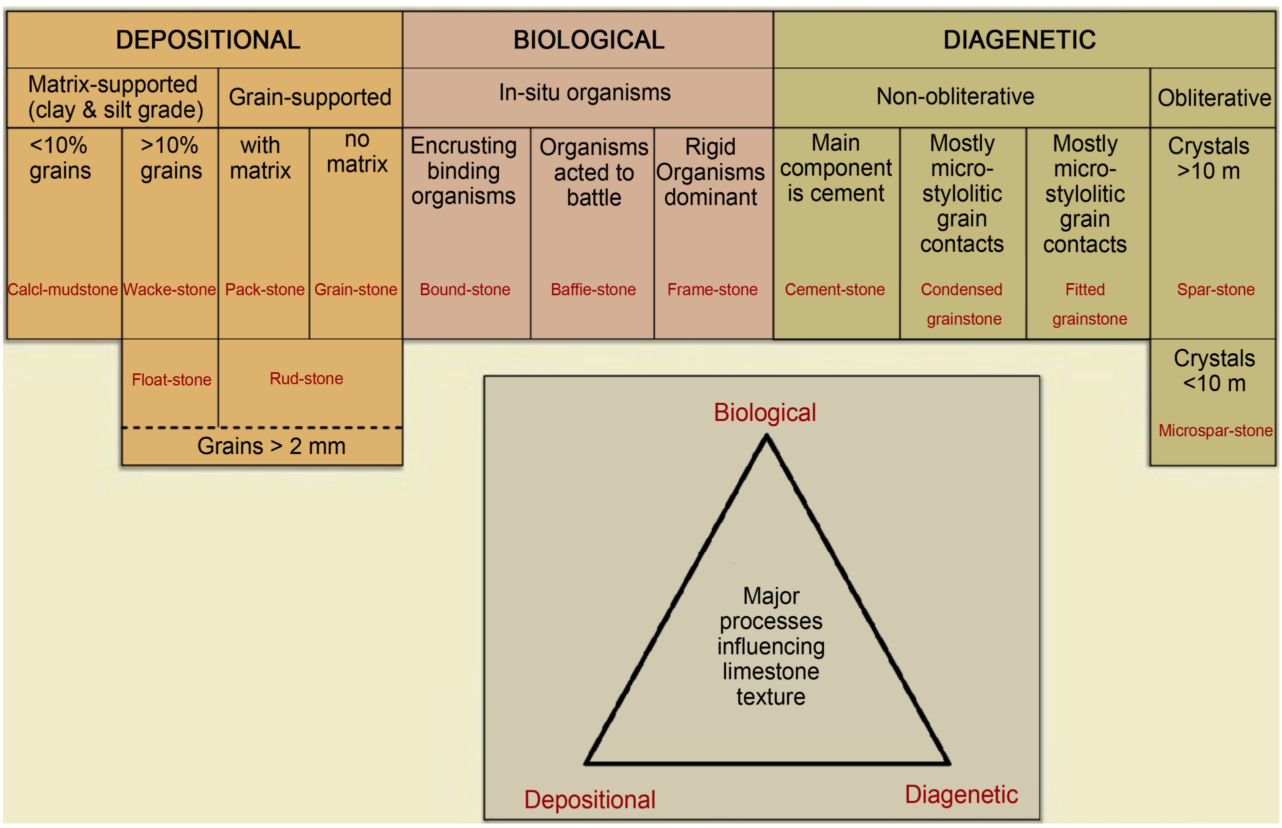

Figure 6. Limestone classification based on the depositional, biological, and diagenetic framework (after Wright, 1992).

Table 3. Calculated values for porosity, specific gravity, and water absorption.

Sample No.	Absorption	Specific gravity (gm/cm^3)	Porosity (%)
SA-1	0.40	2.71	0.38
SA-2	0.37	2.73	0.28
SA-3	0.45	2.72	0.32
SA-4	0.34	2.72	0.31
SA-5	0.31	2.713	0.35
Avg.	**0.374**	**2.7195**	**0.328**
SB-1	0.64	2.81	0.31
SB-2	0.63	2.78	0.33
SB-3	0.64	2.71	0.36
SB-4	0.62	2.68	0.39
SB-5	0.64	2.64	0.41
Avg.	**0.634**	**2.724**	**0.36**

range of values for use as dimension stone and engineering projects. The calculated values of porosity for limestone range from 0.38% to 0.35% with an average value of 0.328% while for marbleized limestone range from 0.31% to 0.41% with an average value of 0.36% (**Table 3**).

The UCS test was performed in the laboratory according to ASTM D-2938 specifications [25], the calculated average value of UCS for limestone is 93.348 MPa while for marbleized limestone 78.82 MPa (**Table 4**). So according to international standards UCS values fall in strong category for construction purposes. Similarly, UTS was also performed in the laboratory according to (ASTM-D397 Standards [28]. The calculated values of UTS for limestone range from 6.9 MPa to 7.28 MPa with an average value of 7.56 MPa while for marbleized limestone ranges from 6.25 to 4.98 MPa with an average value of 5.656 MPa (**Table 4**), the UTS values are within the limits of International Standards. Shear strength of the collected samples of limestone and marbleized limestone were determined indirectly from UCS and UTS values. A common tangent was drawn between the two resultant Mohr circles. Cohesion (C) and angle of internal friction (Φ) are the two factors used to calculate shear strength. The value of (Φ) is given by the angle of tangent with the horizontal axis. The value of C is given by the distance between the points of intersection of the x and y axes and the point where the tangent cuts the y-axis (**Figure 7**). The value of cohesion and internal fraction is different by using different value of UCS and UTS. The calculated average values for the studied samples are.

$C = 3.45$, and $\phi = 31.5^{\circ}$.

Table 4. The UCS and UTS results of limestone and marbleized limestone.

Samples name	Rock type	UCS		UTS	
		Load (N)	Strength (MPa)	Load (N)	Strength (MPa)
SA-1	Limestone	39,279	90.23	3379	6.9
SA-2	Limestone	41,769	96.5	3250	8.15
SA-3	Limestone	40,276	93.4	3045	7.57
SA-4	Limestone	40,410	94.26	3450	7.9
SA-5	Limestone	39,780	92.35	3505	7.28
Average		**40,524**	**93.348**	**3314.5**	7.56
SB-1	Marbleized limestone	34,852	80.1	2686	6.25
SB-2	Marbleized limestone	34,350	79.5	2346	6.1
SB-3	Marbleized limestone	34,095	78.8	2850	5.7
SB-4	Marbleized limestone	33,855	78.2	2015	5.25
SB-5	Marbleized limestone	33,630	77.5	2566	4.98
Average		**34,156.4**	**78.82**	**2516**	**5.656**

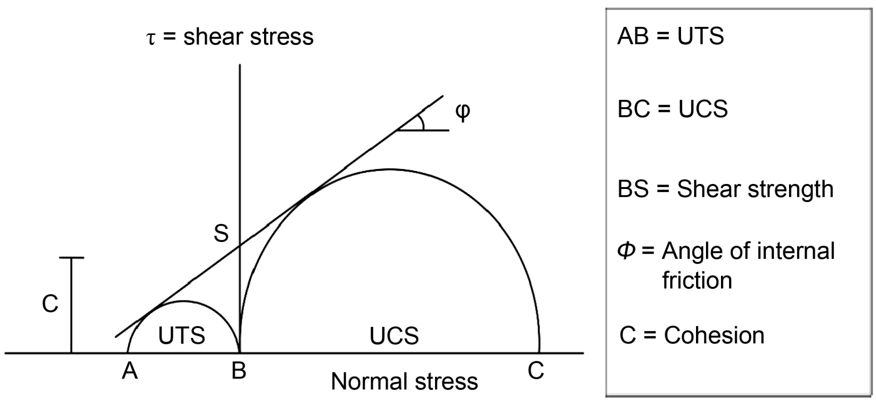

Figure 7. Measurement of shear strength from UCS and UTS.

5.2. Petrography Analysis

According to the [37], the diagenetic basis Limestone is subdivided on diagenetic features into non-obliterative and obliterative. The non-obliterative are further classified into cement stone, condense grain stone, and fitted grain stone which is characterized by the main component as a matrix, many micro-stylolitic grains contacts and mostly micro-stylolitic grains contacts respectively. The obliterative are classified to spar stone and micro-spar stone with having greater and less than 10 μm crystals size respectively (Figure 8).

5.2.1. Stylolitic Spar Stone (Marble)

The marble composed of the large size orthorhombic and massive calcite crystals. The crystal size is ranging from 0.05 mm to 1.5 mm. Most of the grains are

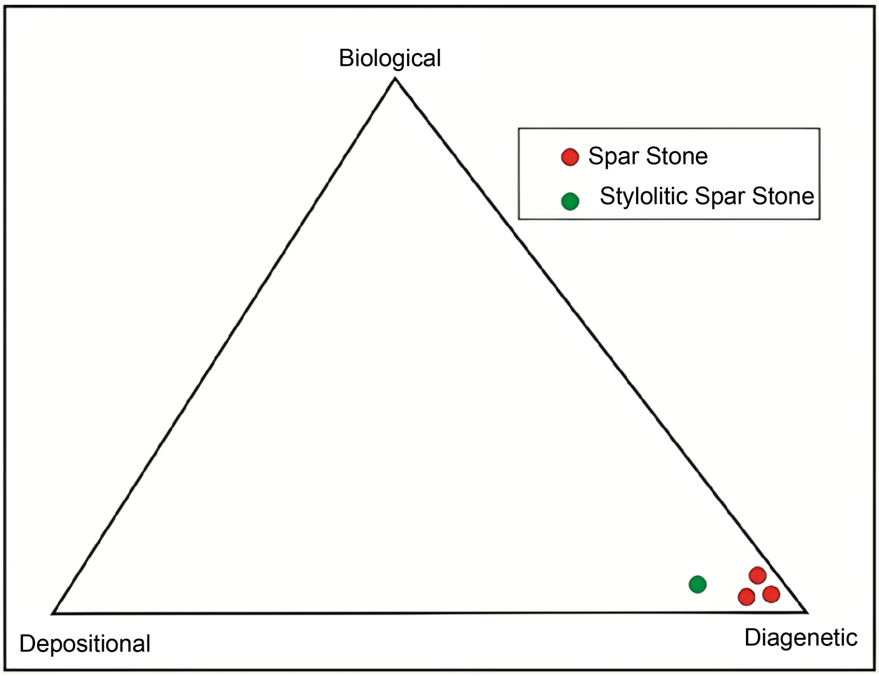

Figure 8. The model composition of the marble/limestone based on Wright 1992 classification.

coarse with grains showing subhedral to euhedral shape. The calcites crystals have perfect sets of cleavages which clear under both plane-polarized and cross-polarized light (**Figure 9**). At the 75˚ the cleavages intersect under the cross light. The twinning is observed under the cross-polarized light along the cleavage's surfaces (**Figure 9**). The crystals relief is very low under the plane-polarized light. The relief is changing with stage rotation through 360˚. The effect is called twinkle effect of the calcite crystals. The calcite crystals are colorless/white under the plane-polarized light while having varieties of color under the cross-polarized light.

Apart from the calcite crystals, opaque minerals are observed which are probably pyrites. The grains of the pyrites are in a considerable amount where it is ranging up to 2% model composition.

The stylolites are observed in the thin section view. The stylolites are large in size and crosscut all the crystals and other diagenetic fabrics.

5.2.2. Spar Stone (Marble)

The marble/limestone is composed of large size crystals with fine matrix. The crystals size is ranging from 0.1 mm to 1.2 mm. The crystals are orthorhombic and massive. Most of the grains are coarse with grains showing subhedral to euhedral shape. The grains have perfect rhombohedral cleavages. The sets of cleavages are clear under the plane light. Under the cross-polarized light, the twinning is observed along the cleavages surface (**Figure 10**). The cleavages intersect at 75˚ under the cross-polarized light. The relief is low to very low under the plane light. The crystals are colorless/white under the plane light while having

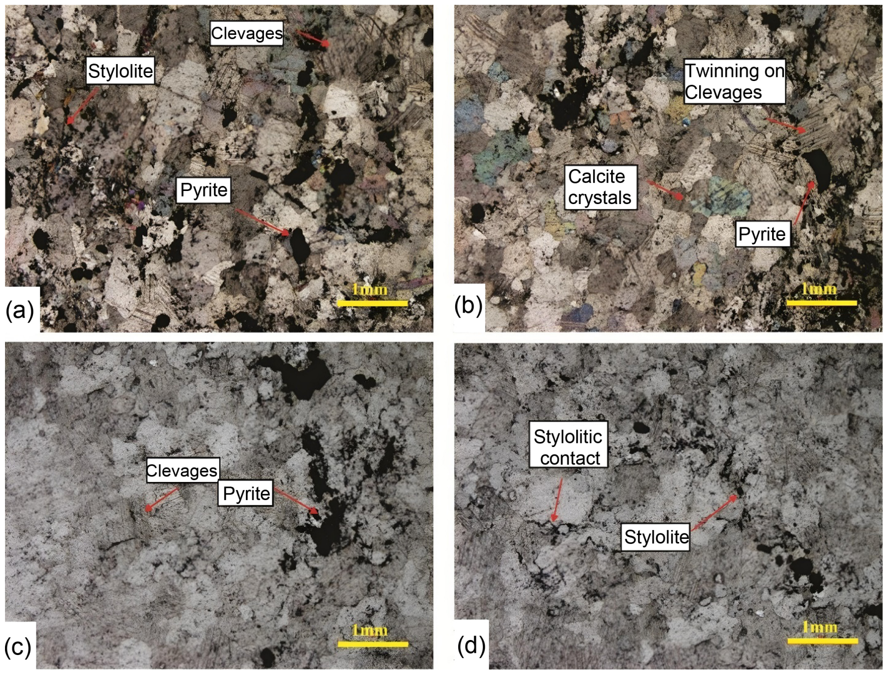

Figure 9. The stylolitic spar stone marble/limestone. Micrographs (a) and (b) show the stylolites, twinning, and cleavages by the calcite crystals, with addition to that the dark blank grains are pyrites (XPL); micrographs (c) and (d) show the cleavages.

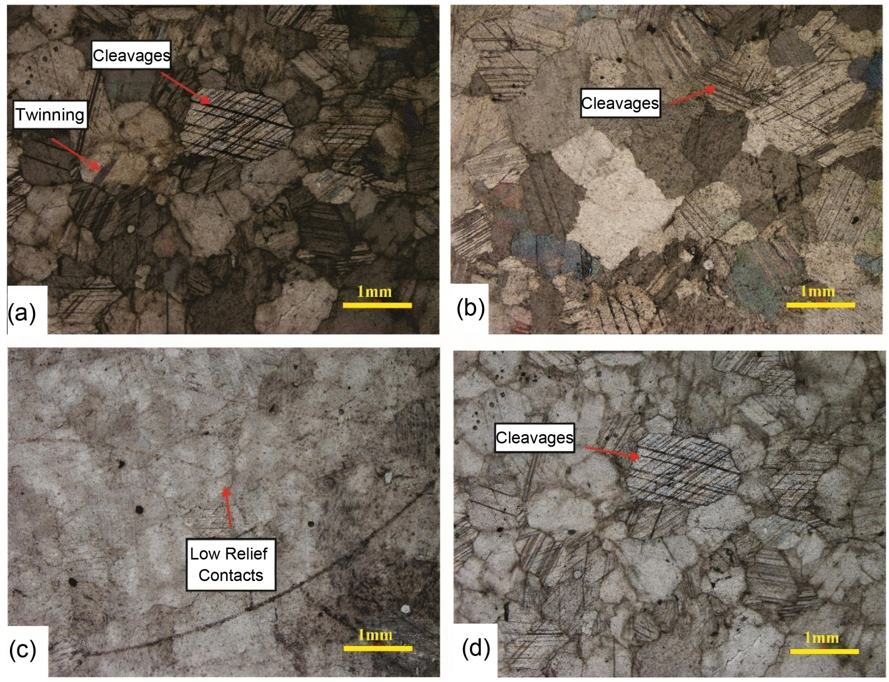

Figure 10. The spar stone marble/limestone. Micrographs (a) and (b) show the twinning and cleavages by the calcite crystals (XPL); micrographs (c) and (d) show low relief and twinning and rhombohedral cleavage of the calcite crystals (PPL).

varieties of colors under the cross light e.g., Pink, bluish, brown and greenish (Figure 10).

5.3. Relationship between Physical and Mechanical Properties

The physical and mechanical parameters of the analyzed rocks are plotted against each other to evaluate any possible relationship. As seen in, the UCS and UTS values of the studied rocks exhibit an inverse relationship with porosity (**Figure 11**), while the UCS and UTS values have a direct relationship with specific gravity (**Figure 12**) and are consistent with those discovered by other researchers such as [38] [39].

6. Conclusion

The current studies focus on the use of NikanaiGhar limestone as a potential aggregate source for construction projects. For determination of physical and mechanical properties, various laboratory tests were performed which include specific gravity, water absorption, shear strength, porosity, uniaxial compressive strength, and tensile strength respectively. Thin section study was also conducted

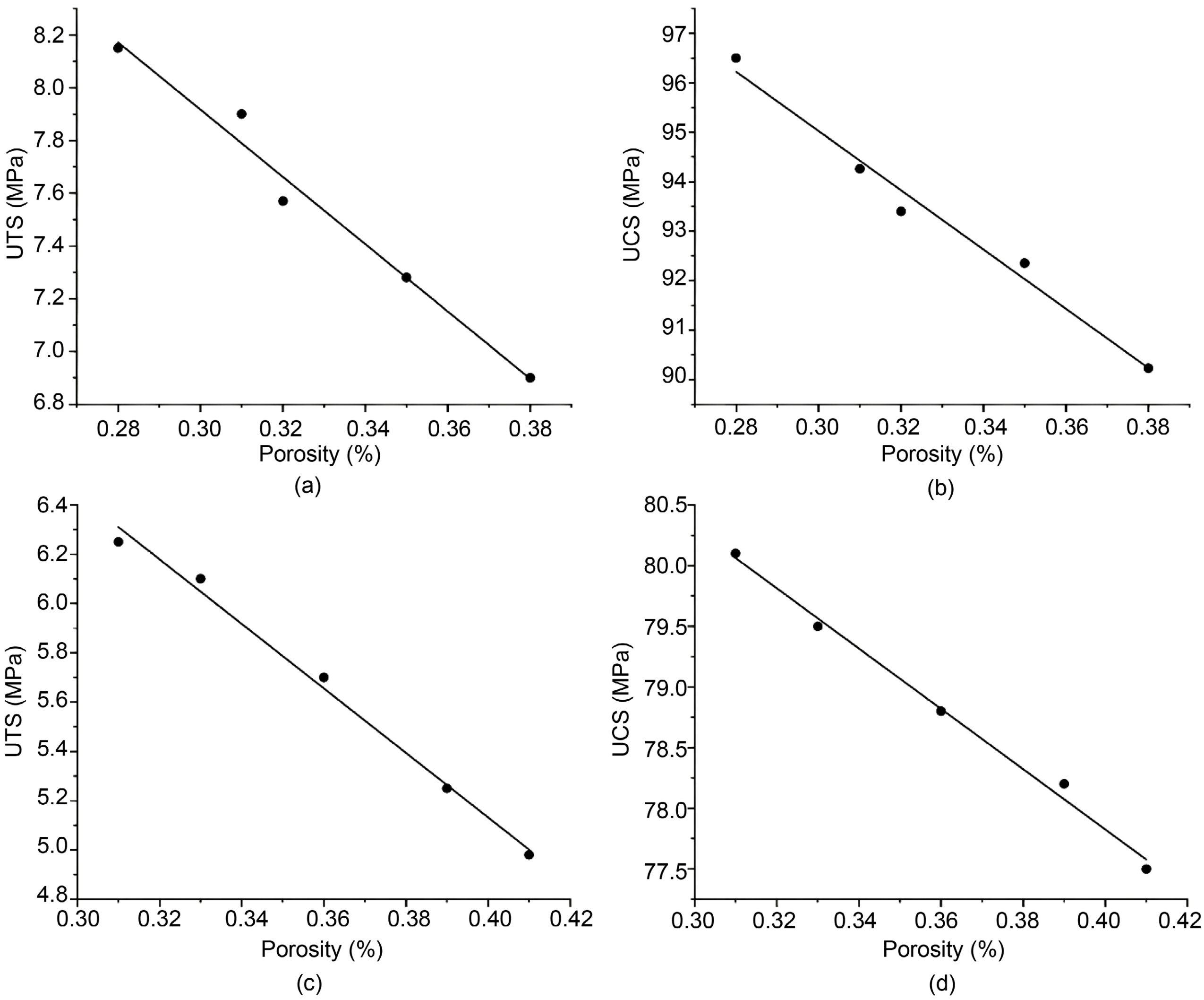

Figure 11. The relationship of UCS and UTS with porosity ((a), (b) limestone and (c), (d) marbleized limestone).

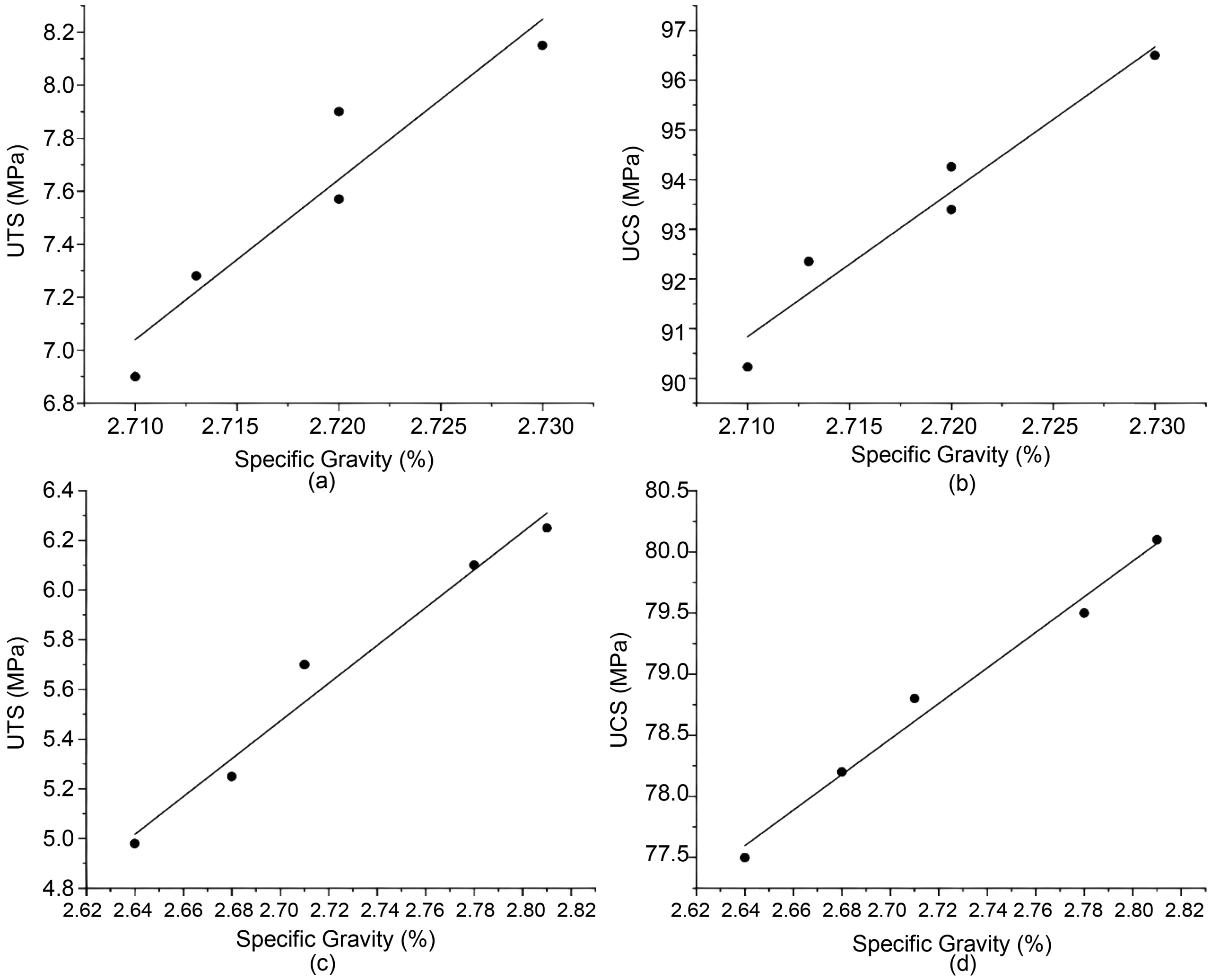

Figure 12. The relationship of UCS and UTS with specific gravity ((a), (b) limestone and (c) Marbleized limestone).

for better understandings of mineral composition of both samples. A detailed petrographic investigation of thin sections shows that two types of rocks are exposed in the study area. Based on the Wright classification, two types of limestone are recognized *i.e.*, stylolitic spar stone and spar stone which are coarse-grained and subhedral to euhedral. The average calculated values of both samples were then compared with international standards for their qualification as an aggregate source. Regression analysis studies were also conducted which showed the co-relationships were in accordance with the previous authors. The calculated results of all physio-mechanical properties are in accordance with the international standard values, which suggest that aggregate can be used for construction projects.

7. Recommendations

More research on the occurrence history of aggregate samples, their structural behavior, and more geotechnical tests are recommended in order to use NikanaiGhar limestone in all types of building work. To identify the many lithological variances in the region, remote sensing-based mapping is required. The increase of crushing enterprises in the region will result in a large amount of potentially usable aggregate. The aggregate material is extracted in Pakistan using the traditional blasting process, which results in a material loss of more than 50%. That's why careful attention to the appropriate processing of the aggregate is essential.

Acknowledgements

The authors would like to say thanks to Sayed Muhammad Iqbal and Mr. Wajid Hussain for their valuable suggestions and proofreading.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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