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An evaluation of the geotechnical characteristics of Gahirat marble using empirical methods: A case study from the Chitral area, Khyber Pakhtunkhwa, North Pakistan

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Abstract

The use of marble as a building or dimension stone is one of the most growing commodities throughout the world. Due to the rapid increase in urbanization, dimension stones are commonly used in building interiors as well as exteriors. Marble, being a metamorphic rock is very desirable to be utilized in structural as well as decorative purposes. The study presented herein evaluates the geotechnical characteristics of the Gahirat marble in the Chitral area, Pakistan. For this purpose, 40 representative samples of the Gahirat marble from ten different vicinities of the Chitral area were collected and tested to determine the correlation amongst the different geotechnical properties of the studied rock. The uniaxial compressive strength (UCS), Brazilian tensile strength (BTS), water absorption, specific gravity, point load strength (PLS), Schmidt rebound hammer, ultrasonic pulse velocity (UPV), and soundness, tests were performed to evaluate the strength of the Gahirat marble for its possible use as a dimension and building stone. An average of 12 measurements for each of the ten rock sample collection vicinities were performed. The statistical analysis shows that a fairly strong linear positive correlation (R2 = 0.80, 0.81, 0.84, 0.92) exists between UCS along with BTS, specific gravity, water absorption PLS and UPV. The maximum values obtained for the 12 measurements regarding the mechanical properties such as UCS, BTS, PLS and Schmidt hammer rebound number were 97.25 MPa, 11.34 MPa, 6.75 MPa and 51, respectively. The maximum values of the physical properties such as water absorption, soundness, specific gravity and UPV tests were calculated to be 0.08%, 0.38, 2.68 and 5.04 km/s, respectively. The results of the uniaxial compressive strength, Brazilian tensile strength, point load strength and Schmidt hammer rebound tests indicate that the Gahirat marble shows high resistance to crushing and bending effects while the specific gravity values indicate its ability to bear the impact of the degree of polishing and grinding. The water absorption and soundness test values indicated that the Gahirat marble is appropriate to be utilized for floor tiles and outdoor cladding due to its resistance against weathering and low rate of the water absorption.

Keywords: Chitral; Gahirat marble; Geotechnical properties; uniaxial compressive strength; Brazilian tensile strength; Empirical correlation; North Pakistan

1. Introduction

Natural stones such as marble, granite, basalt, sandstone, slate, laterite, gneiss, quartzite and limestone have been used extensively as construction material and dimension stone throughout history (Mustafa et al., 2016). Moreover, they are being used for monumental and decorative purposes as well Like sedimentary and igneous rocks, the metamorphic rocks are highly valued and have also great importance for use as a building and dimension stone because of their desirable composition and complex rock fabric (Sajid and arif, 2015; Sajid et al., 2016; Scrivano et al., 2018; El Aal and Kahraman 2017). Marble is mostly considered as a classy, elegant and decorative natural stone used for artistic sculpture making and for building construction on the basis of geo-mechanical properties of marble (Peng et al., 2016; Singh et al., 2015; Jian-bin et al., 2019).

The study area lies in the Chitral district, Khyber Pakhtunkhwa (KPK) province, Pakistan (Fig. 1). This province is blessed with the huge reserves of marble in Swabi, Nowshera, Buner, Mardan, Swat and Kohistan area. The district Chitral is blessed with the huge reserves of grey and white quality marble (Figure 2- a, b). Shakirullah and Afridi, 2004 described the four major deposits of marble in the Chitral District such as Gahirat marble, Reshun marble, Shishi valley marble and Shoghore valley marble. Fahad, 2016 investigated the marble on the basis of physico-mechanical properties along the Mardan-Buner Belt. Mustafa et al., (2015) studied the rocks like marble, granite, limestone, sandstone commonly exploited as building stones in Sub-Himalayas Muzaffarabad, Azad Kashmir region. The marble deposit exposures in the Chitral area are easily accessible and in most of the areas, quarrying of these deposits have already been started (MDDKPK, 2014). In addition to the availability of the marble deposits and ease of quarrying, the Gahirat marble of the Chitral area must fulfil the requirements of geotechnical properties such as strength, durability, hardness, toughness, specific gravity, porosity and absorption, finishing and appearance to ensure its suitability as a dimension and building stone.

2. Geological Setting

Tectonically, the area is located on the southern side of the Pamir Block in the north of the Chitral (Tahirkheli, 1979). The rocks exposed in the Karakoram Block are situated between the Indus Tsangpo Suture Zone (ITSZ) in the northern side and the Indus Suture Zone (ISZ) in the south (Gaetani et al., 1996). In the north of ISZ, the Chitral area is distributed in two geological zones on the northern and southern sides of the Reshun fault (Pudsey et a1., 1985). The northern zone comprises the Chitral slates, the Koghozi greenschist, the Gahirat marble, the Krinj limestone, the Reshun Formation and the Karakoram Block The rock units are comprised of a Permo-Carboniferous Darkot group of slates and quartzose sandstone, the Cretaceous Gahirat marble and Krinji limestone, Koghozi greenschist, Jurassic Chitral slates, and the Tertiary Reshum formation (Fig. 1; Desio, 1959; Calkins et a1., 1981). The Cretaceous Gahirat marble is a thick complex of white to ash grey, massive and coarsely crystalline marble (Fig. 2; Desio, 1959). Pudsey et al. (1985) described this formation as a massive light grey coarsely crystalline marble.

The Cretaceous Gahirat marble is a thick complex of white to ash grey, massive and coarsely crystalline marble. The marble contains dominantly calcite along with the accessory minerals such as muscovite, phlogopite, chlorite and ore minerals. It is mainly exposed near the Chitral city and its surrounding areas (Fig. 1). It is exposed in bands and separated by grey micaceous phyllite towards the Drosh-Chitral road section.

3. Materials and Methods

3.1 Sample collection

The detailed fieldwork was carried out for geological rock sampling and outcrop observation in August 2017 (Fig. 1). Forty representative rock samples from ten different vicinities of the Chitral area such as Chinar, Goja Lasht Khairabad, Kesu, Birir, Gang Gahirat, Gahirat Gol, Gumbat and Domun were collected based on their exposure and variations. These variations were occurred in the rock quality on the basis of various colors, textures and geo-mechanical characteristics that make their high possibility to be utilized as a building stones. The rock samples were observed for macroscopic defects to ensure that the specimens were intact, free of visible cracks, flat and unweather.

3.2 Sample preparation

For the geotechnical analysis, rock samples were prepared in the laboratory for testing. The cores of the samples were prepared as per the requirement of the specified test. The geotechnical analyses were conducted following the specifications of the American Society for Testing and Materials (ASTM) standards. The geotechnical tests included uniaxial compressive strength (UCS), Brazilian Tensile Strength (BTS), specific gravity, water absorption, Point Load Strength Test (PLS), Schmidt rebound hammer, ultrasonic pulse velocity (UPV) and soundness tests. All these laboratory tests were performed at the geotechnical laboratory of the Institute of Geology, the University of Azad Jammu and Kashmir, Muzaffarabad, Pakistan.

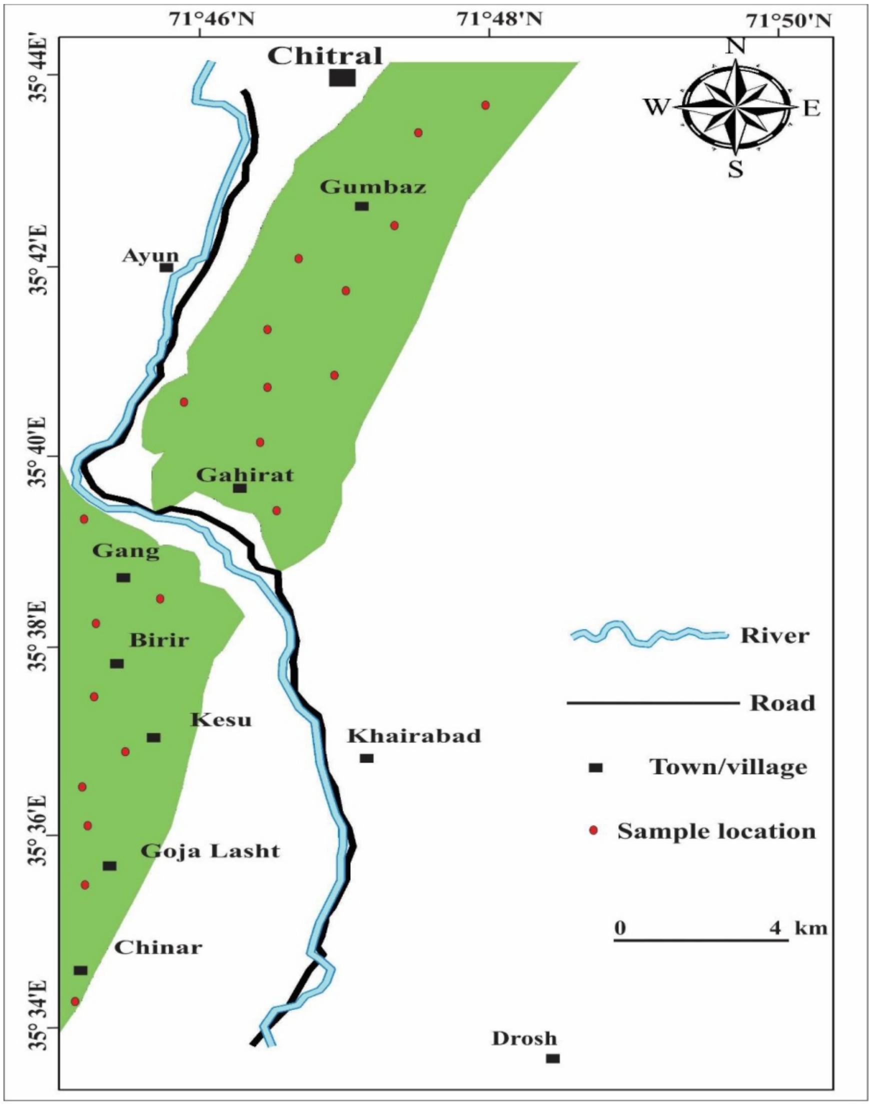

Fig. 1. Geological and location map of the study area after Khan and Khan (2000) and Calkins et al. (1981). GMC= Chinar Gahirat Marble, GMGL= Goja Lasht Gahirat Marble, GMKB= Khairabad Gahirat Marble, GMK= Kesu Gahirat Marble, GMB= Birir Gahirat Marble, GMG= Gang Gahirat Marble, GMGT= Gahirat Gahirat Marble, GMGG= Gahirat Gol Gahirat Marble, GMGz= Gumbat Gahirat Marble, GMD= Domun Gahirat Marble.

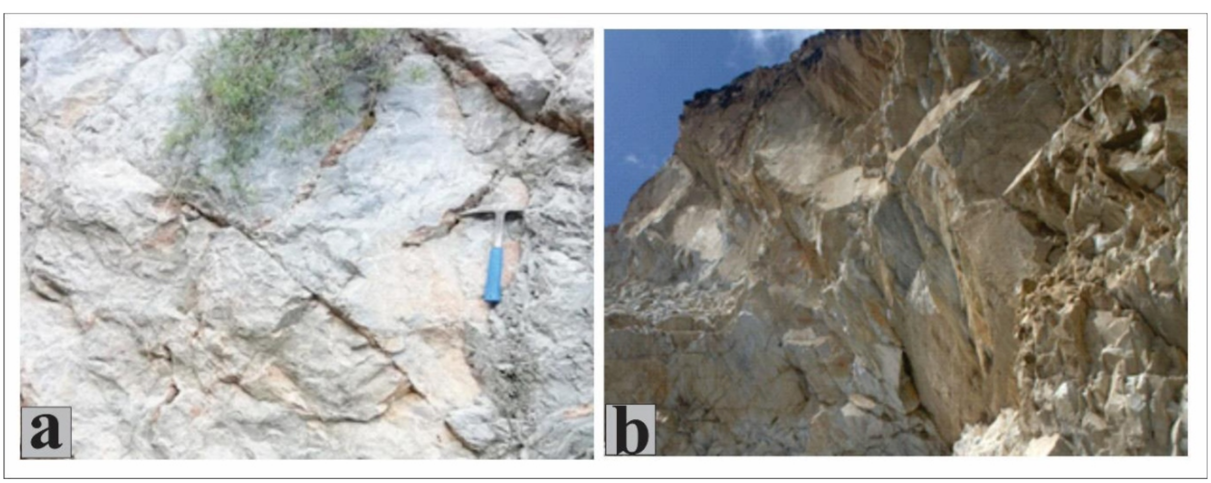

Fig. 2. (a) Field photograph showing an outcrop of the Gahirat Marble near Gahirat area. (b) Light grey color Gahirat Marble exposed along the roadside near Khairabad area.

3.3 Laboratory tests

The UCS and BTS tests were performed following the ASTM standards C170/C170M–17 and ASTM D3967–16, respectively. Based on these tests, the rock was characterized based on its strength and durability since these are the two significant parameters that are essential to evaluate every type of building stone (Sims, 1991). Besides, the UCS and BTS were also useful to check the mechanical soundness of a rock (Mustafa et al., 2016).

The UCS and BTS tests were conducted on 40 representative cylindrical Gahirat marble rock cores with lengths (L) of 98.4 mm, diameters (D) of 49.2 mm and length-to-diameter ratios (L/D) of 2.0 in most cases to calculate the strength of the rock. On average, 3 cores were tested for each rock sample by using a CONTROLS Model No. C56B02 rock UTM machine with a capacity of 3000 kN following the ASTM specification (Fig.3). The uniaxial compressive strength values reported in Table 1 represent average values of twelve measurements for each vicinity of the Chitral area. The BTS is an indirect test to determine the tensile strength of the rocks. According to Liang et al. (2015), the measurement of the splitting tensile strength by the BTS gives replicable results, where the test is mainly used due to its low price and its ease (Altindag and Guney, 2010).

Specific gravity and water absorption tests were conducted as per the ASTM C97/C97M – 18 standard. The rock samples were saturated in water for 48 h and then were completely dried at a temperature of 60 °C. The water absorption is the ratio of the capacity of the rock specimen to absorb water to the weight of the dry Specimen.

The point load strength (PLS) test is also used to indirectly determine the uniaxial compressive strength of the rock (Karakus and Tutmez, 2006; Franklin, 1970; Bieniawski, 1975; Bell, 2007; Kohno and Maeda, 2011). Rock samples collected from the field were prepared for testing as per the ASTM D5731 – 16 standards. For this purpose, samples were trimmed and the surfaces were smoothened following the relevant ASTM standard to determine the UCS for each rock core sample. A minimum of 3 cores for each rock sample were tested for PLS to determine the strength of the rock. The results reported an average of twelve measurements for each of the representative locations of the Gahirat marble (Table 1).

Schmidt rebound hammer value is being used for testing the rebound surface of hardened concrete and rocks (Schmidt, 1951). The test provides a rapid estimation of the compressive strength. The Schmidt rebound hammer test was performed according to the ASTM D5873 – 14 standards on samples obtained from the field. Before testing, it was confirmed that the samples that were collected from the field were intact (unweathered, free of cracks, voids and flat). At least four rebound values were determined for each sample and the average value was used to calculate the UCS.

The soundness test was performed using 350 g of sodium sulphate (Na2SO4) in 1 litre of water. After the samples were submerged in this solution for 16-18 h and then subsequently weighed, they were placed in the oven for a period of 24 h to dry out and then weighed again. Subsequently, the immersion and drying cycles were repeated 5 times on the same sample with a solution change after each cycle. The obtained values were checked with the ASTM D5240/D5240M - 20 standard.

The UPV test (ASTM D-2845) was also carried out on the rock samples prior to unconfined compressive strength test (UCS). The test was conducted on oven dried samples to measure the effect on wave velocity.

3.4 Statistical analysis

The test results of the Gahirat marble for each rock sample was assessed to determine the coefficient of determination. The purpose coefficient of determination (R^2) is to develop reliable interrelations among various geotechnical properties of rock to help in simplifying the process of testing the rocks. The regression results showed that there were two tailed relationships among variables. In other words, the coefficient of determination tells one how well the info fits the model. The relationship among different tests was evaluated to understand the relation between the rock properties. Correlation and regression analysis were used to understand the variability of test results. The results of the UCS were correlated with other tests such as BTS, PLS, UPV, specific gravity and water absorption tests. The correlation coefficient and the best-fit equation were calculated using regression analysis.

4. Results and Discussion

4.1. Geotechnical analysis

The Geotechnical analysis used for evaluation of the materials or rock for their suitability used as dimension stones or construction building material. These evaluations based on determining the rock properties through laboratory testing, in-situ testing during field exploration etc. The following are the laboratory testing being performed on the basis of ASTM standards

4.1.1 Uniaxial compressive strength (UCS) tests

The average values of the UCS of the Gahirat marble of the Chitral area that were determined for each locality are presented in Table 1. The values represent an average of four rock sample tests at each vicinity. The UCS values range from 84.66 MPa to 97.25 MPa. The highest UCS value was obtained in Sample GMKB (97.25 MPa) from the Khairabad area, while the lowest value was obtained in Sample GMD (84.66 MPa) from the Domun area. All rock samples were classified based on UCS ranges presented followed ISO 14689-1, 2003. Based on the classification of the rock material, all UCS values fell into strong category. The results of the UCS measurements on rock samples that were collected from different vicinities of the Chitral area indicate that there is a minor variation in the uniaxial compressive strength values.

Table. 1. Values obtained from laboratory analyses. The values represent an average of four rock sample tests at each vicinity.

S.#	Sample ID	Location	UCS (Mpa)	BTS (Mpa)	Sp.grv.	W.Ab (%)	PLS (Mpa)	Sch. H. Test (Av. N values)	UPV (km/s)	Soun. Test (%age)
1	GMC	Chinar	86.4	9.95	2.46	0.08	4.70	45.8	4.50	0.38
2	GMGL	Goja Lasht	92.2	9.99	2.57	0.05	5.63	46.8	4.79	0.27
3	GMKB	Khairabad	97.25	11.27	2.68	0.035	6.75	50.0	5.04	0.18
4	GMK	Kesu	85.5	9.12	2.50	0.075	4.34	47.75	4.41	0.38
5	GMB	Birir	93.75	10.84	2.66	0.040	6.70	50.5	4.50	0.2
6	GMG	Gang	91.5	9.72	2.66	0.040	5.44	51	4.66	0.22
7	GMGT	Gahirat	91.4	10.02	2.60	0.052	5.82	47.6	4.90	0.27
8	GMGG	Gahirat Gol	93.0	11.34	2.63	0.048	6.03	49.75	4.99	0.24
9	GMG	Gumbaz	91.0	10.13	2.55	0.063	5.83	49	4.74	0.27
10	GMD	Domun	84.66	9.40	2.46	0.076	4.97	44.66	4.42	0.39

4.1.2 Brazilian tensile strength (BTS) test

The average values of the BTS of the Gahirat marble of the Chitral area that were determined for each locality are presented in Table 1. The BTS values range between 9.40 and 11.34 MPa for all of the rock samples collected from the different vicinities of the Chitral area. The highest value of the BTS was determined in Sample GMGG (11.34 MPa) and the lowest value was determined in Sample GMD (9.40 Mpa).

4.1.3 Specific gravity and Water absorption

The average values of the specific gravity of the forty rock samples from the ten different vicinities of the Chitral area are listed in Table 1. The average values of the specific gravity in the rock samples collected from each vicinity ranged between 2.46 to 2.68. The specific gravity values for the majority of the samples were above the minimum value of specific gravity as per the ASTM standard specification (i.e. > 2.5). The maximum specific gravity value was determined as 2.68 for the GMKB rock sample from the Khairabad area, whereas, the minimum specific gravity value was determined as 2.46 for the rock samples GMC and GMD from the Chinar and Domun vicinities of the Chitral area, respectively. The highest specific gravity value found in the Khairabad area was due to the compact nature of the rock and low weathering impact. The water absorption values of each vicinity range between 0.035 and 0.08% (Table 1). All values of water absorption were found in accordance within ASTM C-503 specification (<. 0.20%).

4.1.4 Point load strength and Schmidt hammer rebound tests

The average values of the point load strength tests of each vicinity of the Gahirat marble in the Chitral area are listed in Table 1. The point load strength values range from 4.70 to a maximum of 6.75 MPa. The maximum value was observed for Sample GMKB of the Khairabad marble and the minimum value was noted for Sample GMC of the Chinar area. The Schmidt hammer rebound test was used to determine the hardness of the samples that were collected from the Gahirat marble of the Chitral area. A maximum Schmidt hammer rebound test value of 54 was obtained for Sample GMG whereas a minimum value of 41 was obtained for Sample GMD (Table 1).

4.1.5 UPV and soundness

The values of the UPV tests that were performed in a dry condition ranged from 4.41 to 5.04 km/s (Table 1). The minimum value of UPV tests was observed in Sample GMK from the Kesu area and the highest value was observed in Sample GMKB from the Khairabad area. The soundness values of the Gahirat marble ranges from 0.18 to 0.39% in each vicinity (Table 1). The maximum soundness value was found for sample GMD from the Domun vicinity (0.39%), whereas, the minimum value was found for the sample GMKB from the Khairabad area (0.18%).

4.2 Relationship between the different properties of the rock samples

A bivariate correlation was performed amongst the various properties of the rock samples that were collected from different vicinities of the Chitral area (Table 2). A significant relation (R2= 0.81) was observed between specific gravity and the strength of rock samples recovered from Gahirat marble (Table 2). The fig. 3-a shows that the high values of UCS the higher the specific gravity. The bivariate correlation validated the strong positive correlation (Pearson correlation = 0.779 to 0.901) between specific gravity and UCS, BTS, PLS, UPV along with the Schmidt rebound hammer value (Gupta and Sharma, 2012). However, a strong inverse correlation was observed between specific gravity and the water absorption (Pearson correlation = -0.989) and a strong relation was noted between UCS and the water absorption of rocks (R2 = 0.84; Fig. 3). A strong inverse correlation (Pearson Correlation = −0.79 to −0.989) was found between water absorption and the other strength measures of the rocks (Table 2).

A strong relation exists between UCS and BTS (R2=0.84) (fig. 3-d). The bivariate correlation also confirms a strong positive correlation (Pearson correlation =0.778 to 0.960) between UCS vs. specific gravity, BTS, PLS, UPV and Schmidt rebound hammer number. A strong relation exists between UCS and BTS (R^2=0.84). A strong inverse correlation (Pearson correlation = -0.957) was observed between UCS and water absorption (Table 2). Likewise, a strong positive correlation (Pearson correlation = 0.717 to 0.934) was noted between BTS and specific gravity, water absorption, BTS, PLS, UPV and Schmidt rebound hammer number. The values observed during the PLS also showed a strong inverse correlation between water absorption and point load strength (Pearson correlation = -0.943, R^2=-0.92) (Table 2; Fig. 3), however, the bivariate correlation (Pearson correlation =0.775 to 0.960) confirmed the positive strong correlation amongst other properties of rock and point load strength (Nuri et al., 2012).

Table 2. Bivariate correlation amongst the different properties of the rocks

Correlations								
		Sp.gravity	W.absorption	UCS	BTS	PLS	S.Hammer	UPV
Sp.gravity	Pearson Correlation	1	-.989**	.901**	.779**	.885**	.811**	.823**
	Sig. (2-tailed)		.000	.000	.000	.000	.000	.000
	N	40	40	40	40	40	40	40
W.absorption	Pearson Correlation	-.989**	1	-.917**	-.794**	-.902**	-.796**	-.838**
	Sig. (2-tailed)	.000		.000	.000	.000	.000	.000
	N	40	40	40	40	40	40	40
UCS	Pearson Correlation	.901**	-.917**	1	.917**	.960**	.778**	.895**
	Sig. (2-tailed)	.000	.000		.000	.000	.000	.000
	N	40	40	40	40	40	40	40
BTS	Pearson Correlation	.779**	-.794**	.917**	1	.934**	.717**	.814**
	Sig. (2-tailed)	.000	.000	.000		.000	.000	.000
	N	40	40	40	40	40	40	40
PLS	Pearson Correlation	.885**	-.902**	.960**	.934**	1	.775**	.852**
	Sig. (2-tailed)	.000	.000	.000	.000		.000	.000
	N	40	40	40	40	40	40	40
S.Hammer	Pearson Correlation	.811**	-.796**	.778**	.717**	.775**	1	.682**
	Sig. (2-tailed)	.000	.000	.000	.000	.000		.000
	N	40	40	40	40	40	40	40
UPV	Pearson Correlation	.823**	-.838**	.895**	.814**	.852**	.682**	1
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	
	N	40	40	40	40	40	40	40
**. Correlation is significant at the 0.01 level (2-tailed).								

A strong positive correlation was found between UCS and UPV (R2 = 0.80). Likewise, bivariate correlation confirmed a strong positive correlation (Pearson correlation =-0.823 to 0.895) between UPV and amongst other properties of the rock samples. However, a strong inverse correlation was found between UPV and water absorption (Pearson correlation = R2= -0.838). The moderate correlation (R2= 0.60; Fig. 3c) exists between UCS and the Schmidt rebound hammer number (Fig. 3a and 5f). The bivariate correlation strongly validates a strong positive correlation (Pearson correlation = 0.682 to 0.811) between the Schmidt rebound hammer number and specific gravity, UCS, BTS, PLS and UPV (Table 2). However, a strong inverse correlation (Pearson correlation =-0796) was observed between the Schmidt rebound hammer number and water absorption and UPV.

The tests conducted in the present study included uniaxial compressive strength, specific gravity, water absorption, point load strength, Schmidt rebound hammer, soundness, Brazilian tensile strength and ultrasonic pulse velocity to estimate the strength and the other physical parameters of the Gahirat marble rock samples at each vicinity of the Chitral area. The physical properties, i.e., specific gravity, soundness, water absorption and UPV mainly reflect the mechanical response of the rock samples (Table 1). The mechanical properties such as UCS, BTS, Schmidt rebound hammer number and point load strength tests are considered to determine the strength and durability of rock used for building and dimension stone. The UCS test is a key indicator to determine the compressive strength of rocks (Liang et al., 2015). Likewise, the point load strength test is considered to be the best technique of the classification of material based on strength (Mustafa et al., 2016). In the point load strength test, it was observed that the rock failed along the planar surface as stated by Cargill and Shakoor (1990). They pointed out that it is more closely related to the UCS as compared to the other methods. For establishing an empirical relationship, the Schmidt rebound hammer numbers and compressive strength values are very important (Cargill and Shakoor, 1990). The Schmidt rebound hammer provides very rapid response to estimate the rock hardness and strength of the rock samples both in the field and in the laboratory.

The present research was conducted to reveal the geotechnical characteristics of the Gahirat marble of the Chitral area for its use as a building and dimension stone. It was observed that the rock samples of the Gahirat marble collected from the different vicinities of the Chitral area showed minor variation in the compressive strength (Table 1). The UCS values of the Gahirat marble are relatively higher than the UCS of the Nauseri 66 MPa reported by Mustafa et al. (2015) and the Nikani Ghar marbles as 88 MPa (Max. value) and Fahad et al. (2016) respectively. However, the UCS values of the Gahirat marble are almost similar to those reported by Yasar and Yüzer (2004) and Baker (2017), respectively. Hence, the Gahirat marble presents the highest uniaxial compressive strength as compared to the values obtained for the Nauseri and the Nikani Ghar marbles and can be used as a building and dimension stone. The Brazilian tensile strength values of the Gahirat marble are higher as compared to the values obtained by Mustafa et al. (2015) and Fahad et al. (2016). Similarly, the point load strength values of the Gahirat marble are also higher than the values obtained by Mustafa et al. (2015). However, the values are almost similar to those reported by Cargill and Shakoor (1990). The ultrasonic pulse velocity values of the Gahirat marble are merely less than the findings of Cargill and Shakoor (1990). The specific gravity and water absorption values of the Gahirat marble are merely less than the values reported by Mustafa et al (2015) and Fahad et al. (2016). The obtained specific gravity values indicate a low degree of weathering impact on the studied rocks. Likewise, the lower values of the water absorption tests are probably due to the compact nature of the rock.

An attempt has been made to correlate the results of the rock properties using correlation and regression analysis. The relationships among various rock properties were assessed with the help of the coefficient of determination and bivariate correlation. Fig. 3 indicates that there are strong and positive correlations between specific gravity and the strength of the

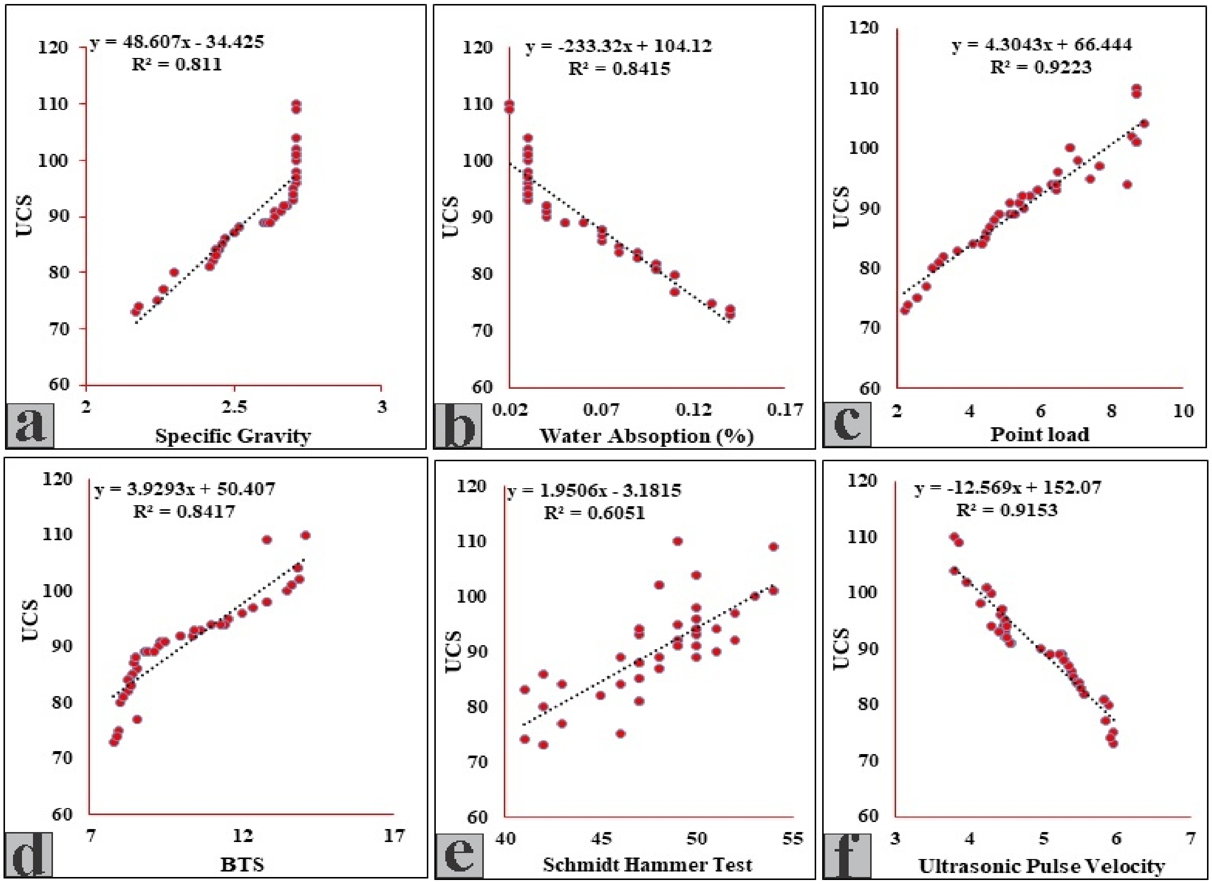

Fig.3. Correlation between the different properties of the rocks. a) Relationship between UCS and Specific gravity, b) Relationship between UCS and Water absorption, c) Relationship between UCS and Schmidt hammer rebound, d) Relationship between UCS and BTS, e) Relationship between UCS and Point load strength, f) Relationship between UCS and Ultrasonic pulse velocity.

rock samples (R2=0.81). A strong inverse relation (R2 = 0.84) was noted between the UCS and the water absorption of rocks. On the other hand, a strong positive relation was found between UTS and BTS (R2 = 0.84). The values achieved for the point load strength test also showed a strong positive correlation between PLS and UCS (R2 = 0.92). Similarly, a strong positive correlation was also found between UCS and UPV (R2= 0.80). A moderate inverse correlation (R2=0.60) was found between UCS and the Schmidt rebound hammer number. Bivariate Pearson correlation confirmed the strong correlation among the different properties of the studied rock (Table 2).

6. Conclusions

The study performed herein evaluates the uniaxial compressive strength and the physical parameters of the Gahirat marble rock samples for each vicinity of the Chitral area. The strength properties indicate that there is a significant strong positive correlation (R2 = 0.81, 0.84, 0.92, 0.80) exist between the UCS vs specific gravity, BTS, PLS and UPV. However, a moderate positive correlation (R2 = 0.60) exists between UCS and the Schmidt rebound hammer number. A positive strong inverse correlation was observed between UCS and water absorption (R2 = 0.84). All UCS values fall in the "strong classification" as per the standard. The highest values of the mechanical properties for an average of 12 measurements for each vicinity were: uniaxial compressive strength (97.25 MPa), Brazilian tensile strength (11.34MPa), point load strength (6.75 MPa) and Schmidt hammer rebound number (51). The maximum values of the physical properties were determined as specific gravity (2.68), water absorption (0.08%), soundness (0.38) and UPV (5.04 km/s).

The results showed that the characteristics of the Gahirat marble in the current study areas are favourable for the architectural purposes in various construction industries. The UCS results indicate that the Gahirat marble has a high resistance to crushing and bending effects. The specific gravity values show its ability to bear the impact of the degree of polishing and grinding. The low rate of water absorption makes it appropriate for floor tiles and outdoor cladding due to its resistance against weathering. Based on these values, the Gahirat marble of the Chitral area is suitable to be used as a dimension and building stone due to its sufficient geotechnical and physical characteristics.

The extraction of local stones on a commercial scale will contribute to the local economy's growth. By minimizing waste, pollution, and environmental hazards, the decrease of construction transportation costs and the simple availability of stone will improve construction quality and promote environmentally sound building practices.

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Authors' Contribution

Syed Amjad Ali Bukhari, first author, executed field & laboratory work and wrote primary manuscript. Dr. Khawaja Muhammad Basharat supervised field & physical investigations and correcting of manuscript. Haluk Akgün did technical review before submission and proof read of the manuscript. Yasir Sarfraz and Muhammad Tayyib Riaz assisted in the laboratory work and the preparation of map.

References

Altindag, R., Guney, A., 2010. Predicting the relationships between brittleness and mechanical Properties (UCS, TS and SH) of rocks. Scientific Research and Essays, 5 (16), 2107–2118.

ASTM C170, 2017. Standard test method for compressive strength of dimension stone. Annual Book of ASTM Standards, Pennsylvania, 4.

ASTM C503, 2018. Standard specification for marble dimension stone (exterior). Annual Book of ASTM Standards, Pennsylvania, 5.

ASTM C97, 2018. Standard test methods for absorption and bulk specific gravity of dimension Stone. Annual Book of ASTM Standards, Pennsylvania, 4.

ASTM D2845, 2020. Standard test method for laboratory determination of pulse velocities and Ultrasonic elastic constants of rocks. Designation. Annual Book of ASTM Standards, Pennsylvania, 7.

ASTM D3967, 2016. Standard test method for splitting tensile strength of intact rock core Specimens. Annual Book of ASTM Standards, Pennsylvania, 5.

ASTM D5731, 2016. Standard method for determination of the point load strength index of Rock. Annual Book of ASTM Standards, Pennsylvania, 11.

ASTM D5873, 2014. Standard test methods for Schmidt Hammer Test of dimension stone. Annual Book of ASTM Standards, Pennsylvania, 4.

Austrominera, 1978a. Mineral exploration and mine development, Chitral district. Report for Sarhad Development Authority, Peshawar, Pakistan.

Baker, M. B., 2017. The application of marble and granite as building material in Jordan. Jordan Journal of Civil Engineering, 11 (2), 234-238.

Bell, F. G., 2007. Engineering Geology. Second edition Elsevier, 278–288.

Bieniawski, Z. T., 1975. Point load test in geotechnical practice. Engineering Geology, 9 (1), 1–11.

Calkins, J. A., Jamil Uddin, S., Bhuyan, K., Hussain, A., 1981. Geology and mineral resources of the Chitral- Partsan area, Hindu- Kush range, Northern Pakistan. United State Geological Survey, 716, 1-29.

Cargill, J. S., Shakoor, A., 1990. Evaluation of empirical methods for measuring the Uniaxial compressive strength of rock. International Journal of Rock Mechanics and Mining Sciences & Geo-mechanics Abstracts, 27(6), 495-03.

Desio, A., 1959. Cretaceous beds between Karakoram and Hindu Kush Range

(Central Asia). Italian Journal of Paleontology and Stratigraphy, 65, 221 - 229.

El Aal, A.A., Kahraman, S., 2017. Estimation of durability aspects of Al Masjid Al-Haram Marble, Makkah City, Saudi Arabia, Geotechnical Geological Engineering 35, 2763–2779.

Eren, O., Bahali, M., 2005. Some engineering properties of natural building cut stones of Cyprus. Construction and Building Material. 19, 213-222.

Fahad, M., Iqbal, Y., Riaz, M., Ubic, R., Abrar, M., 2016. Geo-mechanical properties of marble deposits from the Nikani Ghar and Nowshera formations of the Lesser Himalaya, Northern Pakistan. A review of Himalayan Geology, 17 (1), 17-27.

Franklin, J. A., 1970. Observations and tests for engineering description and mapping of rocks. Proceeding 2nd International congress of Rock Mechanics Belgrade, 1, 1-3.

Gaetani, M., Angiolini, L., Nicora, A., Sciunnach, D., Le Fort, P., Tanoli, S., Khan, A., 1996. Reconnaissance geology in Upper Chitral, Baroghil and Karambar districts (northern Karakorum, Pakistan). Geology of Rundschau, 85, 683–704.

Gupta, V., Sharma, R., 2012. Relationship between textural, petro-physical and mechanical Properties of quartzite; a case study from northwest Himalaya. Engineering Geology 135-136, 1–9.

International Standard Organization (2003) 14689-1 (E) Geotechnical investigation and testing identification and classification of rock. Part 1: Identification and description. International organization for standardization, Geneva, 1–16.

Jian-bin L., Zhong-jian Z., Biao, L., 2019. Microscopic & macroscopic characterizations of Beijing marble as a building material for UNESCO heritage sites: New insights into physico-mechanical property estimation and weathering resistance. Construction Building Material, 225, 510–525.

Karakus, M., Tutmez, B., 2006. Fuzzy and multiple regression modelling for evaluation of Intact rock strength based on point load, Schmidt hammer and sonic velocity. Rock Mechanics and Rock Engineering, 39 (1), 45–57.

Khan, M. A., Khan, A., 2000. Geological map of the Chitral district NWFP Pakistan. District Map series, Geology Survey of Pakistan, NWFP, 1.

Kohno, M., Maeda, H., 2011. Estimate of uniaxial compressive strength of hydrothermally Altered rocks from northeastern Hokkaido, Japan, based on axial point load strength test results. International Journal of Japan Common Rock Mechanics, (1), 17–23.

Liang, M., Mohamad, E. T., Khun, M. C., Alel, M. N. A., 2015. Estimating uniaxial Compressive strength of tropically weathered sedimentary rock using indirect test Jurnal Teknologi, 72 (3), 49–58.

Luodes, H., Selonen, O., Paakkonen, K., 2000. Evaluation of dimension stone in gneissic rock-a case study from southern Finland. Engineering Geology, 52, 209–223.

Minerals Development Department, Khyber Pakhtunkhwa MDDKPK, 2014. Geology, known Metallic minerals and gemstones together with information on past exploration coverage in Chitral region.

Mustafa, S., Khan, M. A., Khan, M. R., Hameed, F., Mughal, M. S., Asghar, A., Niaz, A., 2015. Geotechnical study of marble, schist, and granite as dimension stone: a case study from parts of lesser Himalaya, Neelum Valley Area, Azad Kashmir, Pakistan. Bulletin of Engineering Geology and Environment, 74 (4), 1475–1487.

Mustafa, S., Khan, M.A., Khan, M.R., Sousa, L.M.O., Hameed, F., Mughal, A., Niaz, A., 2016. Building stone: a case study of Sub- Himalayas, Muzaffarabad region, Azad Kashmir. Pakistan. Bulletin of Engineering Geology and Environment, 209, 56–69.

Pascoe, E. H., 1923. General report of the Geological Survey of India for the year 1923: India Geological Survey Records, 55, 1-51.

PASDEC., 2010. Trade Development Authority of Pakistan A Report on Marble and Granite.

Peng, J., Rong, G., Cai, M., Yao, M. and Zhou, C., 2016. Comparison of mechanical properties of undamaged and thermal

-damaged coarse marble under triaxial compression. International Journal of Rock Mechanics and Mining Sciences, 83,135-139.
Pudsey, C. J, Schsoeder, R. & Skelton, P. W., 1985. Cretaceous (Aptiad-Albian) age for island Arc volcanic, Kohistan, North Pakistan. Contribution to Himalayan Geology, 3, 150-168.
Sajid, M., Arif, M., 2015. Reliance of physico-mechanical properties on petrographic characteristics: consequences from the study of Utla granites, north-west Pakistan. Bulletin of Engineering Geology and the Environment, 74, (4), 1321-1330.
Sajid, M; Coggan, J; Arif, M; Andersen, J; Rollinson, G., 2016. Petrographic features as an effective indicator for the variation in strength of granites. Engineering Geology, 202 44-54.
Schmidt, E., 1951. Quality control of concrete by rebound hammer testing (Versuche mit dem neuen Beton-Prüfhammer zur Qualitätsbestimmung des Betons). Schweiz Arch angew Wiss Tech 1951; 17, 139–143.
Scrivano, S., Gaggero, L., Gisbert, J., Aguilar, 2018. Micro-porosity and minero-petrographic Features influences on decay: Experimental data from four dimension stones, Construction Building Material, 173, 342–349.
Shakirullah, Afridi, I. M., 2004. Mineral development profile of North West frontier Province and the role of directorate general mines and minerals in the minerals Resources development. Geol. Bull. Univ. Peshawar, 37, 139-154.
Sims, I., 1991. Quality and durability of stone for construction. Quart. Journal of Engineering Geology 24, 67-74.
Singh, R., Bhutani, M. & Syal, T., 2015. Strength evaluation of concrete using Marble Powder and Waste Crushed Tile Aggregates. International Journal for Science and Technologies, 20(1), 18- 28.
Tahirkheli, R.A.K., (1979) Geology of Kohistan and adjoining Eurasian and Indo-Pakistan Continents, Pakistan, Geology of Kohistan, 1-3: Special Issue Geology, University of Peshawar, 11.
Yasar, E., Yüzer, E., 2004. Estimation of rock physic-mechanical properties using hardnes Methods. Engineering Geology, 71, 281-88.