Evaluating the Effects of Textural Properties on the Strength Parameters of Marbles from North-Western Khyber Pakhtunkhwa, Pakistan

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Abstract: Marble is globally used as a natural stone for decorative and architectural purposes. Primary utilization of marble is as building and dimension stones. Mechanical properties and aesthetic aspects are major characteristics of marble and decisive factors for its selection and utilization. It is therefore imperative to evaluate the key strength properties i.e. Uniaxial Compressive Strength (UCS) and Uniaxial Tensile Strength (UTS) of marble before its utilization. These key strength parameters are dependent on textural features of marble. Present study investigates the effect of two key textural features i.e. grain size and grain shape on two key strength parameters i.e. UCS and UTS of marble samples taken from three different regions i.e. Buner, Chitral and Swat in the north western part of Khyber Pakhtunkhwa. Correlation and regression analysis between these textural properties and strength parameters revealed that prominent textural features of grain size and shape can be used as a quick indicator for assessment of strength parameters and as guideline for appropriate utilization of marble.

Keywords: Marble, petrography, texture, correlation, UCS.

Introduction

Marble is used, since ancient times, as ornamental, sculptural, architectural and dimension stone due to its characteristics (Cevheroglu, 2014 and Kyburz et al., 2017). Pakistan is blessed with massive resources of marble occurrences with diverse colours and qualities. The country has an estimated 300 billion tonnes of marble resources (Pakistan Stone Development Company, 2014). Majority of these marble resources occur in Baluchistan and KP provinces including the erstwhile Federally Administered Tribal Areas (FATA). These marble deposits have a diverse geology resulting in a variation in textural features, physical and strength properties. (Tugrul and Zarif, 1999). Therefore, an investigation of textural and mineralogical features in relation to engineering properties of rocks is very important for determining rock strength and resistance to its failure (Irfan, 1996). Characteristics of marble are affected by several factors, like texture, composition, mineralogy, minerals' arrangement, weathering conditions and voids (Vallejo et al., 2011).

Physical properties of marble are mostly dependent on texture, mineralogical composition, geological, deformational and environmental history, and the alteration and weathering processes (Little at al. 2003). Similarly, strength properties of marble are considered before its selection and multipurpose utilization. The properties of marble should be tested before its use in certain conditions and for a certain purpose. To determine a relationship between the physical, textural, mineralogical and strength properties of marble is an active area of research. A close correlation has been observed between strength properties and textural features of rocks which are used mainly as building stone (Liu H et al., 2005; Ozturk et al., 2014; Ozcelik et al., 2004). Different scholars have investigated the effect of textural characteristics on strength parameters of rocks. These characteristics include composition of mineral, grain size and grain shape, degree of cementation and cementation material (Ozcelik et al., 2013).

According to Maharaj (2001), petrographic and geological features affect the strength and engineering behaviour of rocks. According to Quick (2002), the behaviour of rocks can easily be predicted from actual details of mineralogy, texture and other feature of rocks. Ozer et al. (2020) studied physical and mechanical properties of marble deposits including real density, apparent density, total porosity, open porosity, breaking load, compressive strength, flexural strength, rupture energy. A number of statistical findings, linear equations and inequalities were obtained from the physical and mechanical data. Most of the variables were found significantly correlated.

In Pakistan, marble is generally excavated and used hardly taking into consideration any testing of strength properties and engineering behaviour. This lack of characterization may result in an inappropriate selection and use of marble for the specified purpose. The present research work is aimed at evaluating the relationship between key textural and strength

parameters of marble through simple correlation and regression analysis. The correlation and regression analysis between the prominent textural properties (grain size and shape) and strength parameters (UCS and UTS) can provide a quick guideline for assessment of marble and will result in better utilization of marble from usability, economic and safety point of view.

Materials and Methods

Thirty bulk samples were collected from Buner, Chitral and Swat in Khyber Pakhtunkhwa. Ten samples from each site were collected (Fig. 1). Petrographic studies of marble samples were carried out to study the desired textural properties of grain size and shape. A series of thin sections were prepared from the core and hand specimens. Grain size was determined through visual observation under a polarizing microscope. Inbuilt scale of the polarizing microscope was used to determine the grain size. Grain size was classified as fine, fine to medium, medium to coarse grained and graded as 1 (representing fine) to 5 (representing coarse). Similarly, visual observation and grain shape charts were used to identify and number the grain shape as rounded, rounded to sub-round, sub-rounded to sub-angular and angular to sub-angular (graded from 1 to 5). Grain shape was also classified as equi-granular (represented by 1) and non equi-granular (represented as 0). Thin section photographs of marble samples are given (Figs. 2, 3, 4).

Compressive strength is the extreme load absorbed by rock sample before breakage (Quick, 2002). Similarly, a rock's tensile strength is resistance of the rocks to the forces which act for bringing deformations in its shape. It is related to elasticity of the rock (Bell, 2007). Core and disc samples were prepared from bulk samples in laboratory for determining its strength properties according to ASTM / ISRM standards and specifications. Core samples with Length to Diameter (L/D) ratio between 2 to 2.5 were prepared and tested in laboratory for UCS determination. Similarly, UTS was determined in laboratory by preparing disc samples, keeping thickness to diameter ratio of ½.
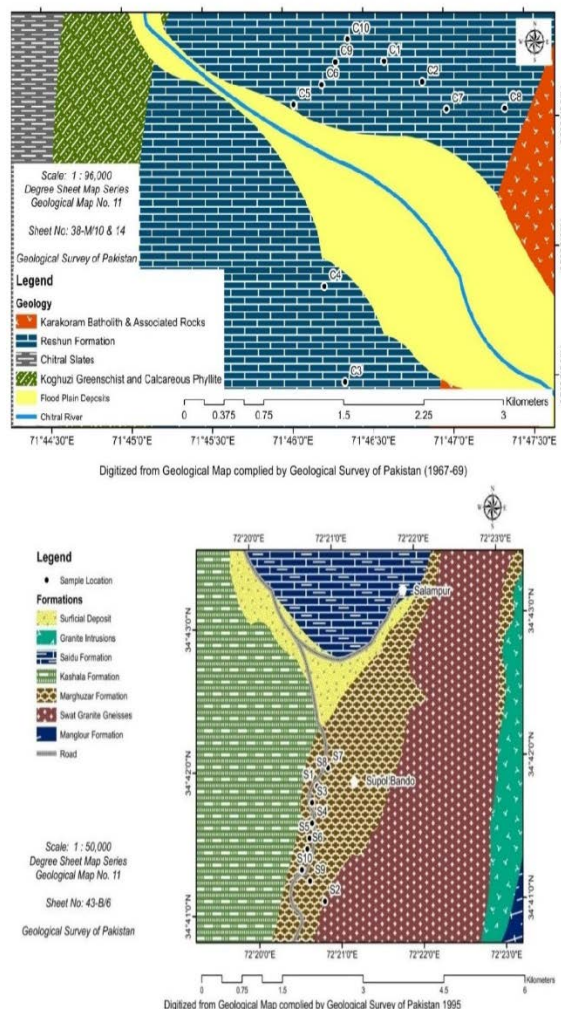

Fig. 1 Geological maps showing lithology, and ample locations from district Buner, Chitral and Swat.
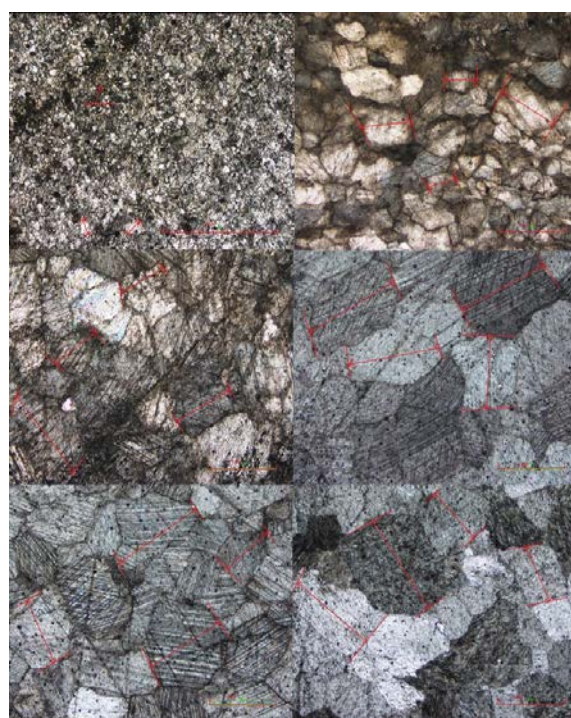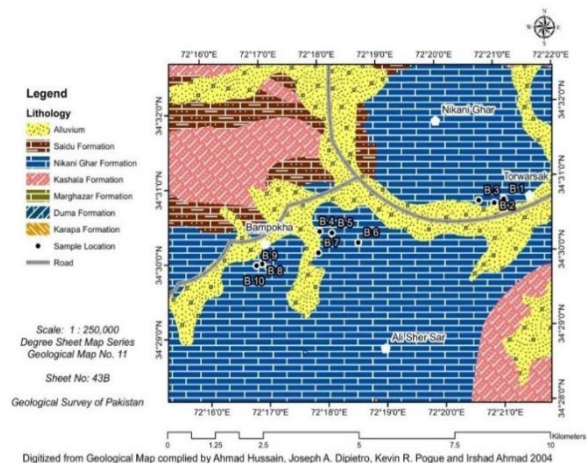

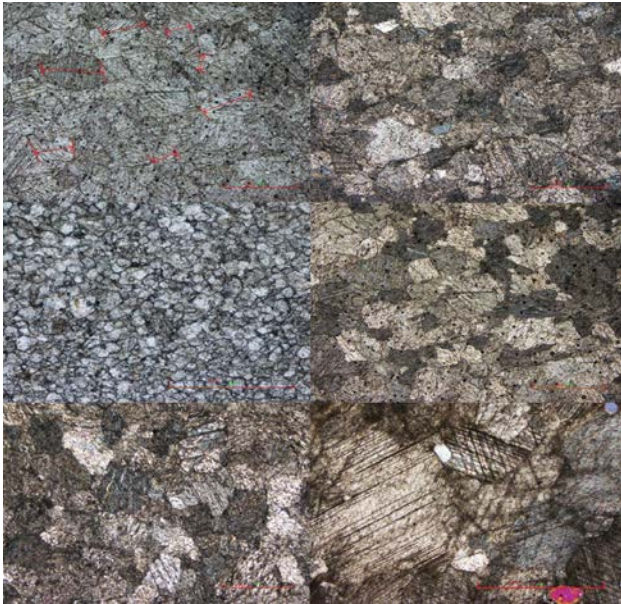Fig. 2 Thin section photograph of marble sample from Buner.

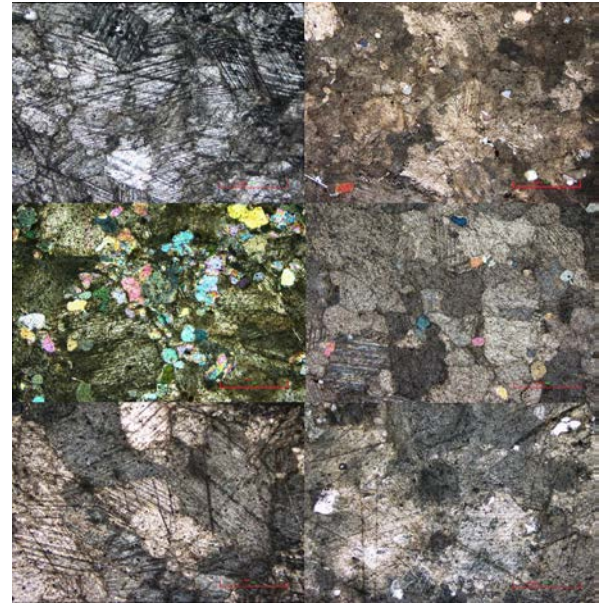Fig. 3 Thin section photograph of marble sample from Chitral.

Fig. 4 Thin section photograph of marble sample from Swat.

Results and Discussion

Results of key textural properties and strength parameters for each sample are presented in Table 1 and 2, respectively. Similarly, scatterplots along with distributions and regression plots along with histograms are presented in Figures 5 and 6 respectively. There is a variation between the observed textural properties and strength parameters of the samples collected from three districts (Tables 1, 2). The results also revealed that there exists a negative correlation between grain size and strength properties. Fine and medium to fine grained samples have higher

UCS and UTS values compared to medium to coarse- and coarse-grained samples. A weaker negative correlation between UTS and average grain size is observed compared to the one between UCS and average grain size. In some samples the grain shape appears to be affecting the UCS and UTS. The effect of grain shape on strength properties is not statistically significant as depicted in the respective scatter and regression plots. Positive correlations are observed within the textural properties (grain size and grain shape) and strength parameters (UCS and UTS).

Table 1 Details of sample locations, grain size and grain shape.

| Sample ID	Sample Location	Grain Size	Grain Shape
B1	Torwarsak (Black)	0.4 - 0.8 mm, Medium to coarse grained	Sub-rounded to sub-angular
B2	Torwarsak (Light grey)	0.09 -0.01 mm, Fine grained and equi-granular	Rounded to sub-rounded
B3	Torwarsak (White)	0.05 mm, Fine grained and equi-granular	Sub-rounded to rounded
B4	Bampokha No.2	1-2 mm, Coarse grained and granular	Sub-rounded to sub-angular
B5			
B6			
B7	Bampokha (Sunny white)	1-2 mm, Coarse grained and equi-granular	
B8	Bampokha No. 1	1.5-2.5 mm, Coarse grained and equi-granular	
B9		1.5-2.5 mm, Coarse grained and granular	
B10			
C1	Gehrait (Light grey)	0.1 to 0.2, Fine grain and equi-granular	Sub-rounded to sub-angular
C2	Gehrait (Grey)		Sub-rounded
C3	Gehrait (Fateh ur Rehman1)	0.1 to 0.5, Medium to fine grained and equi-granular	
C4	Gehrait (Fateh ur Rehman 2)		
C5	Gehrait (Chitral white)	2-3 mm, Coarse grained and equi-granular	Sub-angular to angular
C6			
C7	Gehrait (Chitral Line-Zulfiqar)	0.05-0.1 mm, Fine grained and equi-granular	Sub-rounded
C8			
C9	Gehrait (Chitral line-Usman)	0.1-0.2 mm, Fine grained and equi-granular	Sub-rounded to sub-angular
C10			
S1	Road side near Maosai Tangy	1.5- 2, Coarse grained and equi-granular	sub-rounded to sub-angular
S2		1-3, Coarse grained and equi-granular	Angular to sub-angular
S3	Road side near Spal Bandai	1-1.5, Coarse grained and equi-granular	Sub-angular to sub-rounded
S4			
S5		2-3, Coarse grained and equi-granular	Angular to sub-angular
S6		1-1.5, Coarse grained and equi-granular	Sub-angular
S7	Road side near Maosai Tangy	2-2.5, Coarse grained and granular	Sub-angular to angular
S8		1-3, Coarse grained and granular	
S9	Road side near Spal Bandai	1-2, Coarse grained and equi-granular	Sub-angular to sub-rounded
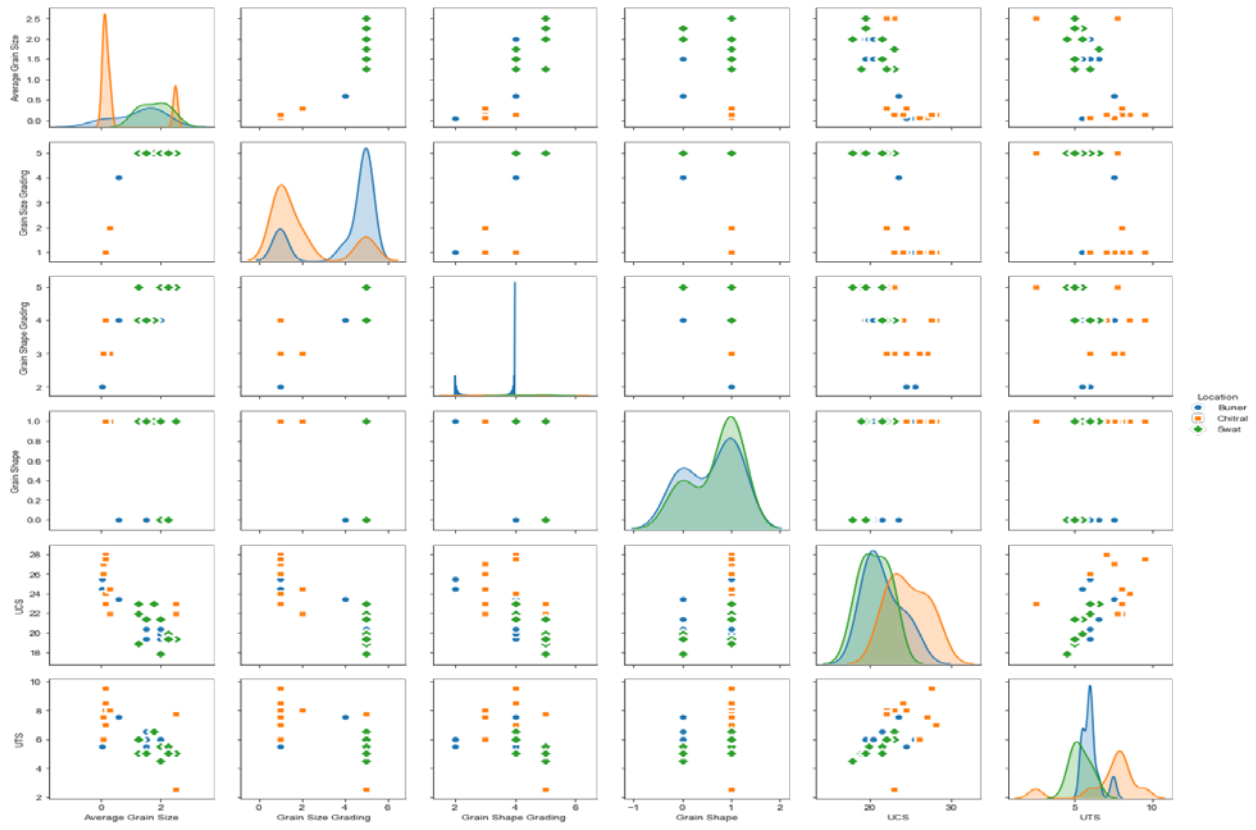
Fig. 5 Scatterplots and distribution of selected textural properties and strength parameters
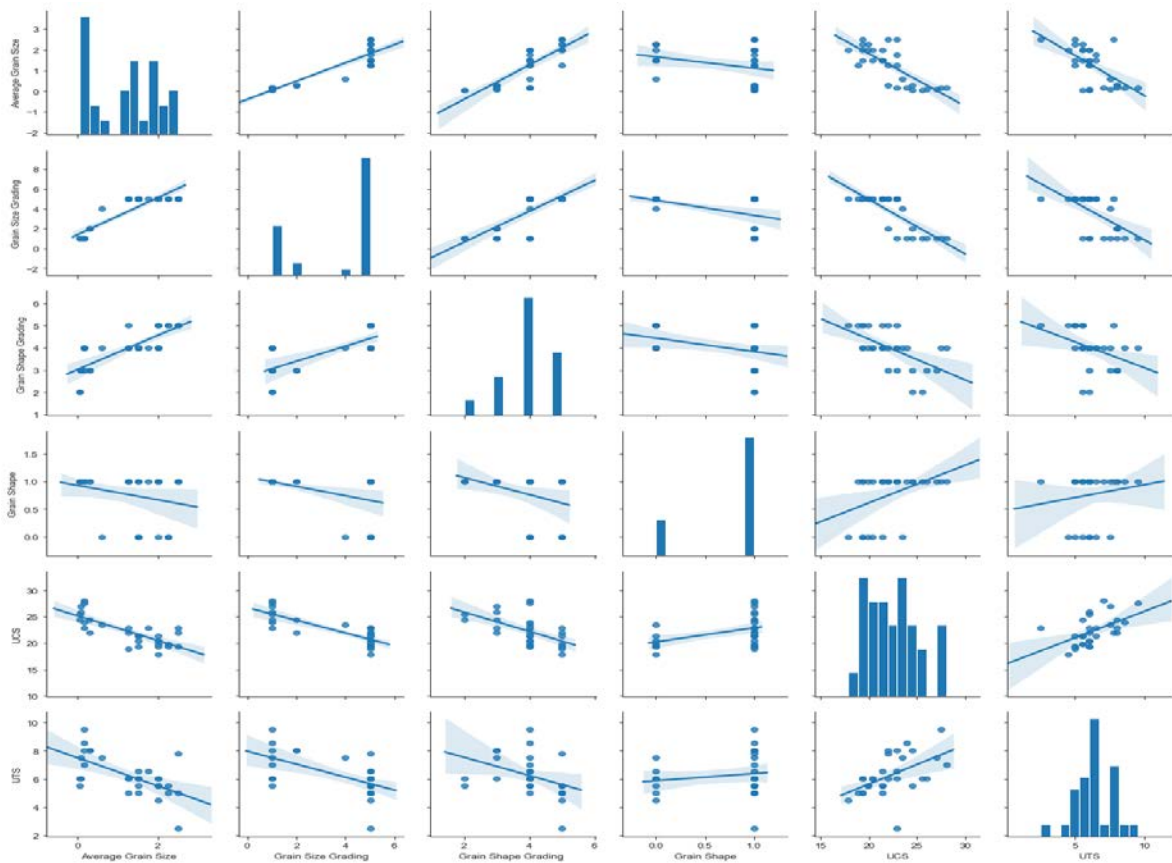

Fig. 6 Regression plots and histograms of selected textural properties and strength parameters.

Table 2. Details of sample locations and strength properties of marble samples.

Sample ID	Sample Location	UCS (MPa)	UTS (MPa)
B1	District Buner	23.44	7.52
B2		25.48	6.02
B3		24.46	5.52
B4		21.4	6.52
B5		19.36	6.02
B6		20.38	6.02
B7		21.4	5.52
B8		19.36	6.02
B9		19.87	5.52
B10		20.38	6.02
C1	District Chitral	23.95	8.53
C2		22.93	8.02
C3		21.91	8.02
C4		24.46	8.02
C5		22.93	6.54
C6		21.91	7.77
C7		27.01	7.52
C8		25.99	6.02
C9		28.03	7.02
C10		27.52	9.53
S1	District Swat	22.93	6.52
S2		21.4	5.52
S3		22.93	6.02
S4		21.91	6.02
S5		19.36	5.02
S6		18.85	5.02
S7		19.87	5.52
S8		17.83	4.51
S9		21.4	5.02
S10		19.36	5.02

These positive correlations between UCS and UTS are very obvious and have statistical significance but the ones between grain size and grain shape can be anecdotal and might need further investigation. Statistically insignificant correlation and regressions are also observed and presented in the respective plots (Figs. 5, 6).

Conclusion

Textural property of grain size can be used as an indicator to assess the two important strength properties i.e. UCS and UTS. Based on this assessment, a guideline can also be developed for proper utilization of marble. Medium to coarse grained Buner marble can be used as building stone and floor tiles while Chitral marble is suitable for multiple purposes i.e. as decorative, architectural and dimension stone. Swat marble has low strength properties and cannot be used for architectural purposes. In order to have a more reliable model to access strength parameters based on the textural properties, more detailed studies are required. Additional textural and strength features should also be tested to investigate the relationship between these properties like mineralogical composition, porosity, abrasion resistance, poison's ratio and Young modulus.

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