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Evaluating the effect of grain size on mechanical parameters of rocks from different areas of Khyber Pakhtunkhwa, Pakistan

Muhammad Tahir, Sajjad Hussain, Zahid Ur Rehman, Noor Muhammad, Muhammad Nazir, Muhammad Sadiq

Department of mining engineering University of Engineering and Technology, Peshawar, Pakistan

**Corresponding authors email: engr.sajjad@uetpeshawar.edu.pk*

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Abstract

Granite is one of the important rocks commonly used as building, dimension and decorative stone. Before using these rocks for any purpose, the mineralogical, petrographic, textural and mechanical properties are important to be evaluated. In this study the effect of textural features on the strength properties especially compressive strength, tensile strength and Hoek- brown parameters, were evaluated of eight different granite deposits from various areas of Khyber Pakhtunkhwa. Hoek – Brown constants (mi and a) were determined for granite of Malakand and Shewa Shahbaz Garhi, using linear regression fitting technique on the full scale laboratory data on established empirical models of Hoek- Brown, Mostyn & Douglas, Generalized Hoek & Brown model, and roclab software. Two linear empirical equations were developed for quantitatively estimation of compressive and tensile strength based on grain size. The result shows that the value of compressive and tensile strength increases when grain size is decreases from very coarse to fine grained and there is little effect of grainn size and texture on the Hoek-Brown failure criterion parameters. It is concluded that the generalized variant of Hoek & Brown failure criterion is more precisely described the behavior of the rock at different stress level.

Keywords: Grain size; Strength properties of rocks; Hoek & Brown constants.

1. Introduction

Amongst the other rocks, granite is used as building stone, dimension stone and decorative stone purpose. The trend of commercial use as decorative stone of granite has been started recently in Pakistan. Keeping in view the importance and potential of Khyber Pakhtunkhwa, Pakistan granite rocks deposits as dimension and decorative stone, the petrographic properties and its effects on physical, mechanical and engineering behavior of granite rocks should be evaluated for the economic viability of future mining of the said rock. Numbers of researchers have been made cataloguing based on petrographic properties of rocks .

The study is focused on the using of textural feature (grain size) as tool for categorizing the granite rocks of eight different locations of Khyber Pakhtunkhwa, Pakistan and its effect on strength properties and engineering behavior of granite rocks. Eight granites of different textural features of Malakand Granite, Shewa Shahbaz Garhi Granite, Ambela Buner Granite, Kumrat Granite, Buffa Granite, Mansehra Granite, Susigali Granite and Utla Granite were used in this study for evaluating the focused study and further the analysis has been carried to check the behavior of the rock at different stress levels.

2. Geology and petrography study of the areas

In the northwest of Himalayas i.e. Peshawar plain, the rocks in the lower swat area is characterized as assemblage of plutonic igneous. The complex is defined as alkaline igneous province , , , , and . In this complex alkaline granite is exposed in Shilman, Warsak, Terbela, Shewa- Shahbaz Garhi, Ambela, Koga and Malakand.

& carried out detailed petrographic studies on various rocks Shewa Shabaz Ghari complex and Ambela granitic complex. In the complex microprophries is very fine grained with orthoclase, perthite, quartz, biotite, magnetite, epidote as major minerals. Alkali feldspar, perthite and orthoclase make up the 84 % of the rock. These minerals occur as microprophyrites stretched along the foliation planes generally parallel to the primary layering. The microprophyroclastics are generally corroded at the margins and their sizes varying from layer to layer. Biotite occurs as small grains thin flakes between quartz and feldspar grains and particularly altered to epidote.

The Ambela granite complex has assorted composition due to intrusion in many phases . The granite in the complex is mainly composed of alkali feldspar, quartz, Plagioclase, muscovite and biotite. Magnetite and sphene occurs are also associated in minor quantities. The Phenocrysts in the granite is feldspar and quartz however, the groundmass consists of Perthtized alkali feldspar, quartz, muscovite and biotite. Thin to thick sheets like fines to coarse grained granite masses of 3-10 m in length are exist in the complex of Ambela granite. Based on investigations found that the Ambela alkali granite have two textural types; a) Megaporphyritic and b) Microporphyritic. Both the textural types of Ambela granite have high specific gravity and low water absorption capacity however; the Megaporphyritic alkali granite has higher specific gravity and lower water absorption value.

In frontal Himalayas, the Malakand granite is the most well-known rock. It has intruded the gneisses and meta-sediments of Cambrian and Precambrian age . The rock is medium to coarse grained and consist of quartz, alkali feldspar and plagioclase as major mineral however, muscovite, biotite, tourmaline, epidote and apatite are also present in minor quantities. The individual mineral grain size within the matrix ranges from 12mm to 0.03 mm . The rock is fractured granular in texture and is least altered however, no fracture/weak surface is seen thin section .

The Shewa Shahbaz Garhi complex is an isolated outcrop consisting of basic and acidic meta-igneous rocks. Based on petrography and chemistry, correlate it with soda granite of Warsak. The petrography shows that the rock is fine grained having white to black color.
The granite of Kumrat area, upper Dir belongs to Kohistan Batholith is sub – equigranular to in-equigranular, coarse to medium grained. However, the orientations of individual gains have definite orientation in the matrix. The granite consists of plagioclase, quartz and alkali feldspar (exclusively orthoclase) with minor amounts of biotite, muscovite, sericite, an opaque ore mineral and trace amounts of apatite. Chlorite The petrography shows that quartz grains are mostly strained and display strong undulose extinction .

Around the area of Mansehra area, granitic rocks occur. Among these, Mansehra granite, Buffa granite and Susigali granite exposed in the area. Granite from Buffa, Mansehra area is blackish to dim white in color due to presence of large proportion of blackish minerals such as biotite. The rock is fracture coarse grain in texture. Mansehra granite exists in the vicinity of Mansehra city is whitish grey color. The texture of the rock varies from very to coarse-grained with diagonal fracture texture. The color of Susigali granite varies from dark grey to dirty white with coarse grained texture . The ground mass of Utla granite mostly fine grained containing recrystallized quartz .

3. Strength properties

The both Ambela granite have very close values of uniaxial compressive and tensile strength despite of significant difference in mineralogy . The Ambela granite has comparatively higher shear strength values than Shewa Shahbaz Garhi granites and Malakand granite. It is also noted that strength values of Malakand granite is low despite of the greater hardness due high quartz content.

Din, Rafiq, & Mohammad (1995) conducted tests on granite samples from Malakand and Shewa Shahbaz Garhi to find uniaxial compressive strength. Results indicate that Malakand granite has lower strength than Shewa Shahbaz Garhi granite. Din & Rafiq, 1997 also carried out tests on granite rock samples from the said areas to establish correlation between the compressive and tensile strength conducted uniaxial compressive and tensile strength tests on intact granite samples from Kumrat area. Table 1 shows results of tests for compressive and tensile strength earlier conducted by different researchers. Table 2 shows a summary indicating grain size and average strength properties of granite from different location mentioned in this study.

The linear regression model was applied on the qualitative data of grain sized obtained from different granite samples for evaluating the effect of grain size on uniaxial compressive and tensile strength. The two equations were developed as shown in figure 1 and 2 respectively for quantitatively analysis of grain size of on uniaxial compressive and tensile strength.

4. Hoek- Brown parameters

Hoek- Brown Parameters especially the value of mi is determined by fitting Hoek-Brown failure criterion to full sale laboratory data including uniaxial tensile strength, uniaxial compressive strength and triaxial compressive tests results. Where triaxial tests results are not available the parameter can be determined from uniaxial compressive σc and tensile strength σt as:

$$m_i = \frac{-\sigma_c}{\sigma_c} \quad (1)$$

Using the average compressive and tensile strength, the mi value for Ambela and Kumrat granite is obtained from equation (1) as given in table 3.

Table 1. Summary of compressive and tensile tests results.

Sr. No	Location /Granite	No. Tests	Uniaxial Compressive Strength (Mpa)		Tensile Strength (Mpa)		Sources
			Avg.	Std. Devi.	Avg.	Std. Devi.	
1	Malakand Granite	04	36.89	5.46	--	--	(Khan, 1995)
		01	27.30	--	3.25	--	(Din, Rafiq, & Nisar, 1993)
		05	26.23	3.70	2.56	1.22	(Din & Rafiq, 1997)
2	Shewa Shahbaz Garhi Granite	04	68.67	28.29	--	--	(Khan, 1995)
		01	57.36	--	5.57	--	(Din, Rafiq, & Nisar, 1993)
		05	56.90	20.95	8.43	2.64	
3	Ambela Buner Granite	12	50.12	5.50	--	--	(Khan, 1995)
		01	102.85	--	5.72	--	(Din, Rafiq, & Nisar, 1993)
		04	33.49	5.29	3.44	0.31	(Arif, Bukhari, Mohammad, & Sajid, 2013)
4	Kumrat Granite	03	49.19	2.21	4.99	0.49	(Arif, Islam, & Rizwan, 2015)
		03	58.51	3.46	5.83	0.07	
5	Buffa Granite	01	10.99	-	1.65	-	
6	Mansehra Granite	01	11.89	-	2.95	-	(Arif, Mulk, Mehmood, & Shah, 1999)
7	Susigali Granite	01	11.35	-	1.34	-	
8	Utla Granite	03	107.83	28.76	6.00	0.36	(Sajid, Coggan, Arif , Andersen, & Rollinson, 2016)

Table 2. Summary of compressive and tensile tests results.

Sr. No	Location /Granite	Average Uniaxial Compressive Strength (Mpa)	Average Tensile Strength (Mpa)	Grain Size
1	Malakand Granite	30.60	2.67	Very coarse grained
2	Shewa Shahbaz Garhi Granite	61.66	7.95	Fine grained
3	Ambela Buner Granite	51.03	6.16	Medium grained
4	Kumrat Granite	49.19	4.99	Medium to Corse grained
		58.51	5.83	Medium grained
5	Buffa Granite	10.99	1.65	Very Coarse grained
6	Mansehra Granite	11.89	2.95	Very coarse grained
7	Susilgali Granite	11.35	1.34	Holocrytaline Coarse grained
8	Utla Granite	107.53	6.00	Fine grained

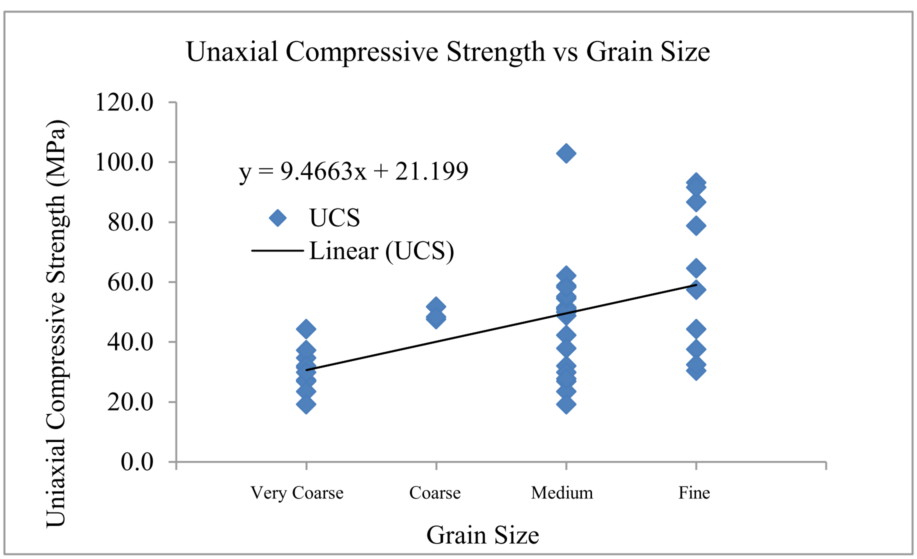

Fig. 1. Effect of grain size on uniaxial compressive strength of granite.

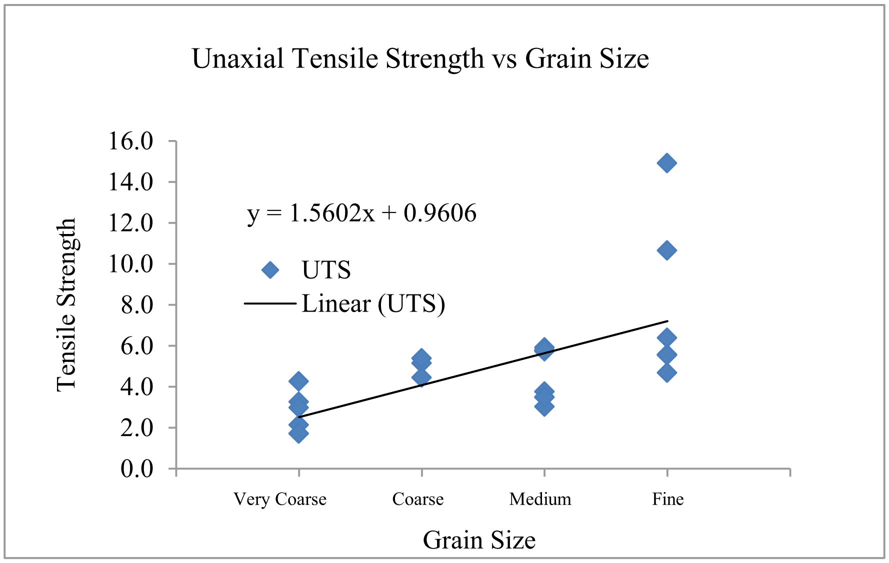

Fig. 2. Effect of grain size on uniaxial tensile strength of granite

Table 3. Hoek-Brown Parameter "mi" values estimated from equation 1.

Sr. No	**Rock**	**Uniaxial compressive strength MPa**	**Tensile Strength MPa**	***mi* Value**
1	Ambela Buner Granite	51.03	6.16	8.3
2	Coarse Grained Kumrat Granite	49.19	4.99	9.8
3	Medium Grained Kumrat Granite	58.51	5.83	10.0
4	Buffa Granite	10.99	1.65	6.6
5	Mansehra Granite	11.89	2.95	4.0
6	Susilgali Granite	11.35	1.34	8.4
7	Utla Granite	107.53	6.00	17.8

In order to obtain more clear picture about the behavior of Malakand and Shewa Shahbaz Garhi granite under various stresses, Din, Rafiq, & Mohammad (1995) conduct triaxial compression strength test on intact rock samples as given in Table 4.

To determine the strength and Hoek-Brown parameters especially "mi" of granite from Malakand and Shewa Shahbaz Garhi, Hoek- Brown failure criterion and its variants were fitted to the test results summarized in Table 1 and Table 2 in Microsoft Excel spreadsheet. Parameters of fitted models i.e. Hoek- Brown (2002) model, Mostyn & Douglas (2002) Generalized Hoek & Brown model and Mostyn & Douglas (2003) Globalized Hoek & Brown model are then optimized through Microsoft Excel Add-in Solver using GRG Nonlinear solving method as shown in figure 3 and figure 4 Results obtained from fitting and optimizations are summarized in Table 5.

Table 4. Results of Triaxial Tests Reproduced from (Din, Rafiq, & Mohammad, 1995).

Location	**Sr. No.**	**Major Principal Stress σ_1 (Mpa)**	**Minor Principal Stress σ_3 (Mpa)**
Malakand Granite	1	60.00	0
	2	101.50	13.00
	3	122.00	18.00
	4	156.00	28.00
Shewa Shahbaz Garhi Granite	1	160.00	0
	2	200.00	10.00

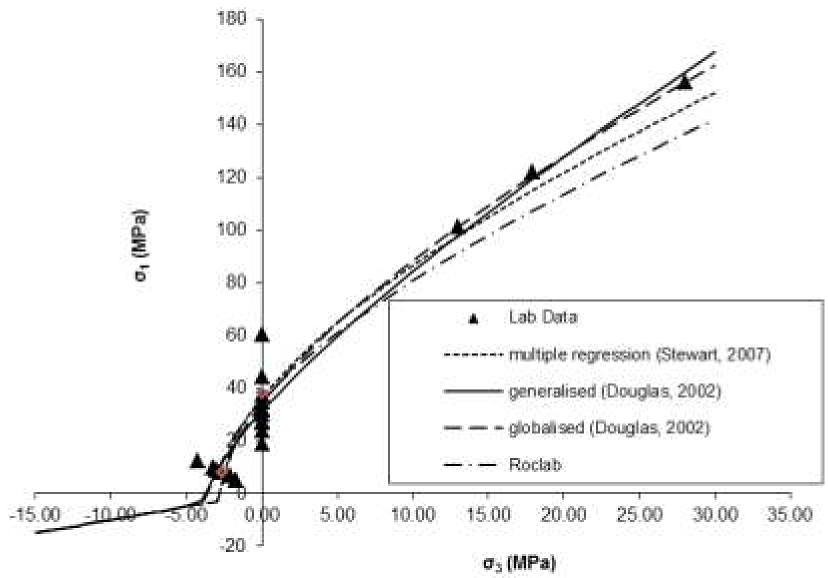

Fig. 3. Fitting of Hoek –Brown Failure Criterion and its variants to intact Malakand Granite.

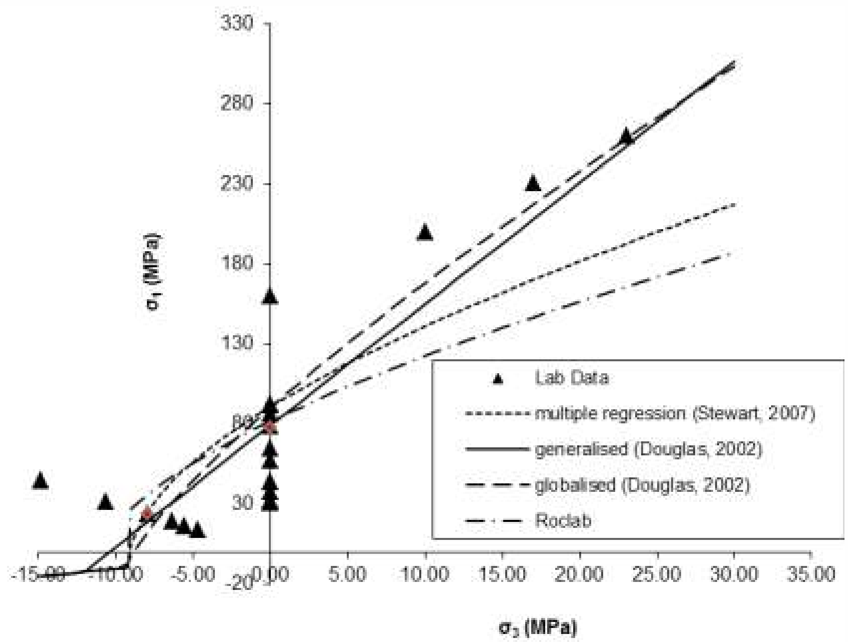

Fig. 4. Fitting of Hoek –Brown Failure Criterion and its variants to intact Shewa Shahbaz Garhi Granite

Table 5. Hoek – Brown Parameters obtained from using various fitting techniques.

Fitting Method	Malakand Granite					Shewa Shahbaz Garhi Granite				
	σ_c	σ_t	m_i	α	Sum of Squares	σ_c	σ_t	m_i	α	Sum of Squares
Multiple regression (Swart 2007)	36.5	-2.9	12.4	0.5	2535	91.0	-9.2	9.85	0.5	42282
Generalised Hoek–Brown (Douglas,2003)	31.3	-4.0	7.8	0.7	1939	79.5	-12	6.6	1.0	24651
Globalised Hoek–Brown (Douglas,2003)	34.2	-2.9	11.6	0.56	1975	90.4	-9.4	9.7	0.77	50721
RocLab Analysis	35.5	-3.3	10.6	0.5	2819	81.9	-9.2	7.3	0.5	45860

5. Discussion and conclusion

It is observed from the analysis of texture/grain size and strength parameters of granite from the selected locations that both the uniaxial compressive and tensile strength is highly dependent upon the grain size of the rock. The strength of granite decreases with increase in grain size. Furthermore, the strength properties also depend upon the crystal/grain orientation in the matrix of rock. It is observed that Malakand granite has least strength. The possible reason is seeming to be heterogeneous coarse grain size and its fracture granular texture comparative to granite from other location.

After comparison of the values of mi for granite form Ambela Buner, Kumrat Upper Dir, Baffa, Mansehra, Susigali and Utla, estimated using equation 1, it is observed that there is minor effect of grain size on the Hoek –Brown parameter mi.

The results of fitting using Hoek –Brown failure criterion and its variants to full scale laboratory tests data of intact granite from Malakand and Shewa Shahbaz Garhi reveal that Globalized variant of Hoek –Brown failure criterion describe the behavior of granite from both the locations. Despite of great difference in grain size, a minor difference in the estimated value of Hoek – Brown parameter is noted.

It is concluded from the analysis of results for selected granite rock in this study that the strength properties of the rock are notably influenced by the grain size. Furthermore, variation in the value of Hoek – Brown parameter "mi" is noted but, not dependent upon the grain size and may be investigated.

Authors' Contribution

Muhammad Tahir, Sajjad Hussain and Zahid Ur Rehman proposed the main concept and involved in write up. Noor Mohammad assisted in establishing sequence stratigraphy of the section. Muhammad Nazir and Muhammad Sadiq collected field data. Zahid Ur Rehman and Sajjad Hussain did provision of relevant literature, and review and proof read of the manuscript. Muhammad Tahir and Noor Muhammad did technical review before submission and proof read of the manuscript.

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