The Nucleus 60, No. 1 (2023) 9-14

https://doi.org/10.71330/thenucleus.2023.1262

www.thenucleuspak.org.pk

The Nucleus

ISSN 0029-5698 (Print)

ISSN 2306-6539 (Online)

Reliance of the Strength of a Sandstone on Petrographic Attributes: A Preliminary Study

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ABSTRACT

For the present preliminary geotechnical investigation, sandstone from Dandot Formation of Permian age has been selected with eighteen samples that were collected for detailed petrographic analysis while three bulk samples were collected for geotechnical analysis. On the basis of grain size sandstone of Dandot Formation was divided into three parts. The lower part was mostly very fine, middle part was generally fine and upper part was of medium grain. Texturally and mineralogically the sandstone was sub-mature. Framework grains in the studied samples essentially consisted of variable amount of quartz (62 to 73%), feldspar (10 to 19%), and rock fragments (3 to 6%). Accessory minerals include muscovite, biotite, iron ore minerals, zircon and glauconite. The cement type in the samples was clayey ferruginous. The modal composition of the sandstone falls in the category of Arkose. The strength test including unconfined compressive strength, unconfined tensile strength, shear strength, specific gravity, and water absorption tests were employed on the rock samples to assess their geotechnical utilities. After evaluating these properties, the acquired test results indicated that the sandstone is very weak and hence cannot be used for construction purposes.

Keywords: *Petrography, Sandstone, Mechanical properties, Dandot formation, Salt range*

1. Introduction

Sandstone has been widely used in architecture works not only restricted to Pakistan but all over the world. Architectural works include both interior and exterior usage. Interior uses of sandstone include countertops, decorative aggregate whereas exterior uses consist of building stone, facing stone, blocks, slabs, tiles and bricks generally used for building walls. Sandstone having good compressive strength and low absorption values are extensively used in foundation for residential and commercial buildings.

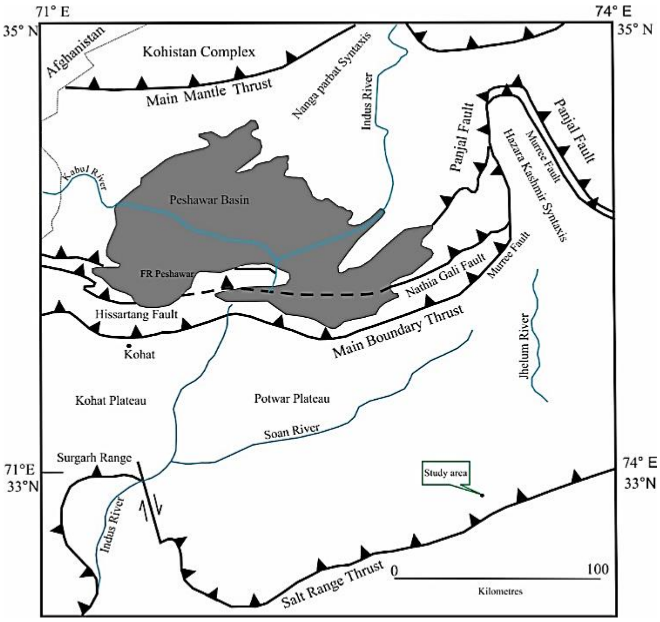

Fig. 1: Tectonic map of North Pakistan. The box demarcates the location of study area [1].

Study area lies at the Choa-Saidan Shah to Khewra road section, Pidh Village, Eastern Salt Range, Upper Indus basin, Pakistan. Dandot Formation is a part of Nilawahan Group of Permian age (Fig. 1). Nilawahan Group consists of four formations (see Table 1).

Dandot Formation comprises of sandstone with shale interbeds. This Sandstone is the main focus of the present study. Sedimentological and Paleontological studies of sandstone from Dandot Formation have been done by various researchers [2-4] while the geotechnical investigation has been carried out for the first time, in order to know whether it is feasible for construction purposes. The current research is of preliminary nature and aimed to know the dependence of strength of sandstone on certain petrographic parameters.

Table 1: Formations detail of Nilawahan Group

	Formations	Lithologies	
Nilawahan Group	Sardhai formation	Clays, shales (variegated colors reddish, greyish, greenish)	Permian Age
	Warchha sandstone	Sandstone containing pebbles of granite (Reddish in color)	
	Dandot formation	Sandstone and shale interbeds (brownish to yellowish)	
	Tobra formation	conglomerates, sandy matrix (brownish in color)	

2. Materials and Methods

Field work was carried out to collect samples from sandstone unit of Dandot Formation for microscopic study. Different lithological characteristics were observed in Fig. 2. Three bulk samples were also collected for preliminary geotechnical examination.

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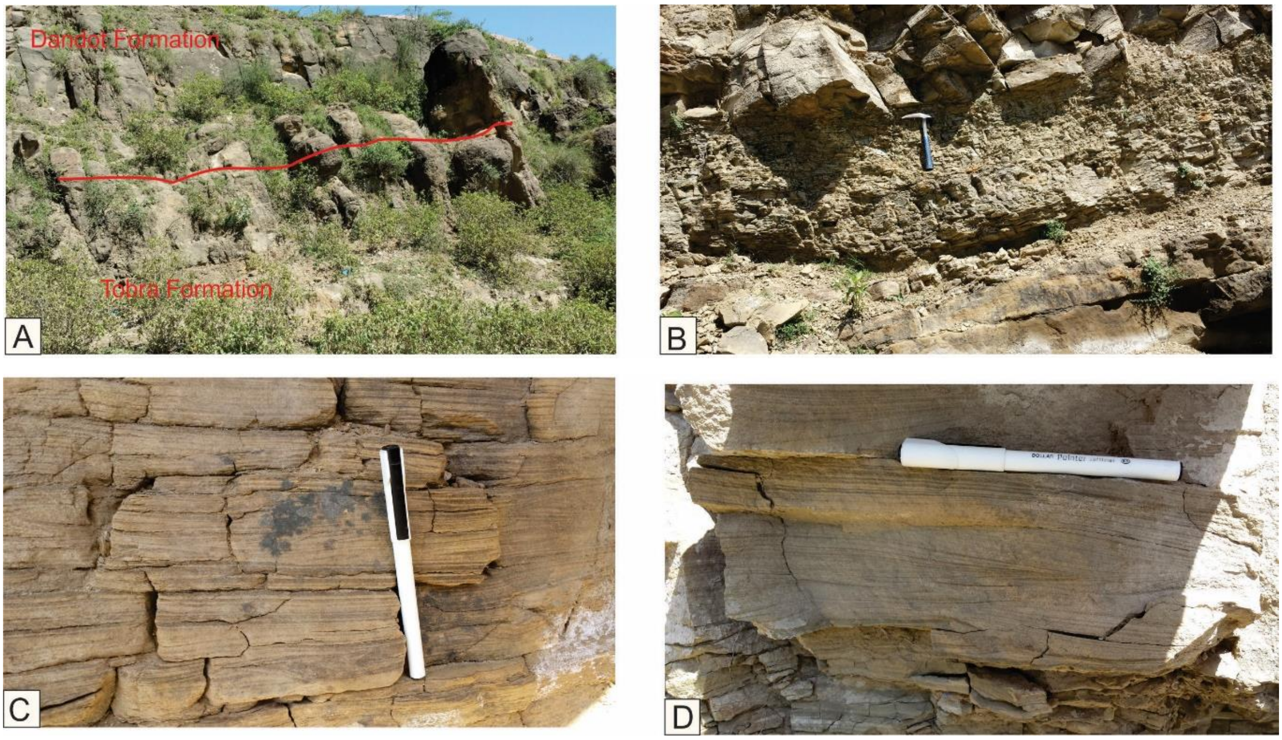

Fig. 2: Field photographs showing contact between Dandot and Tobra Formation (A), interbeds of shale in sandstone (B), Sandstone showing parallel laminations (C), Depicting cross laminations within sandstone unit (D).

Eighteen samples were made into thin sections for petrographic analysis. Among these only nine are selected for microscopic study.

According to the ASTM specifications [5], three cylindrical and three disc-shaped cores for determining Uniaxial Compressive Strength (UCS) and Uniaxial Tensile Strength (UTS) respectively, were drilled from each of the collected block samples. The UCS test was performed directly on these cores. During the present examination the indirect tensile method or Brazilian method [5] was used as it is much simpler and inexpensive [6-10]. Shear strength parameters were determined indirectly in the current study due to its simplicity as stated above in case of UTS. Mohr circles were drawn for the resulting values of UCS and UTS. UCS and UTS readings of the respective sandstone were taken on the positive and negative x-axis respectively. A common tangent to both the Mohr circles was drawn and Cohesion (C) and angle of internal friction (Φ) were determined. The angle of the tangent with the horizontal axis gives the value of Φ while the distance between the x-axis and the points at which the tangent cuts the y-axis gives the value of cohesion (Fig. 3).

The specific gravity and water absorption competence of rock samples were determined and their related information regarding definition and geotechnical importance of the inspected properties, procedure for sample preparation and methods used for their determination are given elsewhere [9-11].

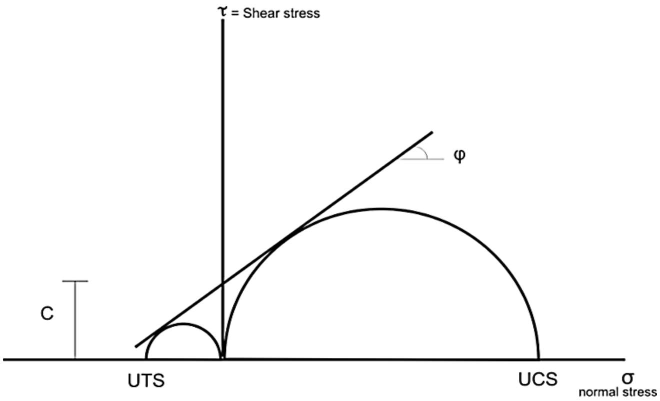

Fig. 3: Represents the indirect measurement of shear strength parameters.

3. Petrography

The petrographic study of sandstone unit of Dandot Formation exposed in Pidh village, Eastern Salt Range is based on the nine (9) representative thin-sections from the selected stratigraphic levels across the formation, where lithologic variations occurred. The data obtained from this petrographic study provides information about textural properties, modal mineralogy and diagenetic changes of the Dandot Sandstone. During present study the framework grains, matrix and cement were identified and relative abundance of each was determined in comparison with visual estimation charts given by [12].

Table 2: Showing textural details of Dandot sandstone

Formation	S. No	Grain size	Roundness	Sorting
Lower Part	D St – 1	Very fine	Angular to sub-rounded	Well
	D St – 2	Very fine	Angular to sub-rounded	Moderate
	D St – 3	Very fine	Sub-rounded	Moderate
Middle Part	D St – 4	Fine	Angular to sub-rounded	Well
	D St -5	Fine	Sub-angular to sub-rounded	Moderate
	D St -6	Fine	Angular to sub-rounded	Moderately well sorted
Upper Part	D St – 7	Medium	Sub-angular to Sub-rounded	Moderate
	D St -8	Medium	Sub-Angular to sub-rounded	Moderately well sorted
	D St - 9	Medium	Angular to sub-rounded	Moderate to well

3.1. *Texture details*

Textural details such as grain size, roundness and sorting are shown in Table 2. On the basis of grain size sandstone unit is divided into three parts. Lower part is very fine grained, middle part is fine grained (Fig. 4A) and upper part is medium grain. Overall the sandstone is moderately to well sorted and grains are angular to sub-angular to sub-rounded (Fig. 4B). In the studied thin-sections tangential and long contacts are common between the grains. The fabric is grain supported.

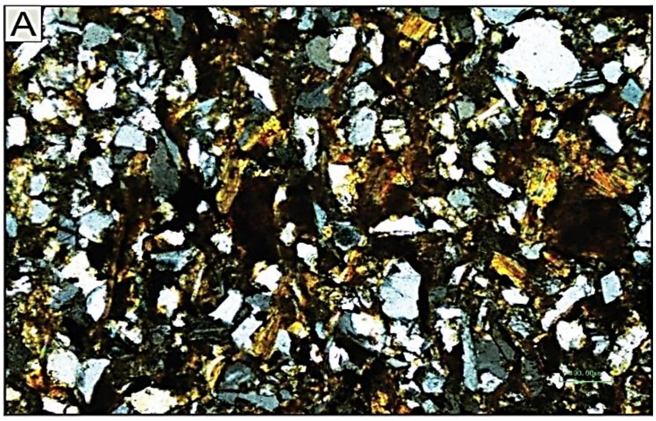

Fig. 4: Photomicrographs (A) indicates very fine to fine grain size PPL whereas (B) shows moderate to well sorting XPL.

3.2. *Modal Composition*

The detailed thin sections study reveals quartz, feldspars, and lithics as framework grains. Micas (muscovite and biotite), zircon, glauconite and opaque minerals are present as accessory minerals. The detailed description of minerals is as follows;

Quartz is present as dominant framework grains in the sandstone of Dandot Formation. The percentage of the quartz ranges from 62 to 73 percent (Table 3). Quartz is present both in monocrystalline and polycrystalline forms. Monocrystalline quartz are the most dominant framework grains in the Dandot Sandstone (Fig. 5A). Mostly monocrystalline quartz grains are unstrained with non-undulatory extinction, but few are present with undulatory extinction commonly known as strained quartz. Microfractures are dominant features noted in quartz grains.

Feldspars are the second most abundant constituent of sandstone. The overall percentage of feldspar (Fig. 5B), including plagioclase and K-feldspars, ranges from 19 to 54 percent (Table 3). Plagioclase is more dominant than K-feldspars. Mostly plagioclase shows albite polysynthetic twinning (Fig. 5C). Majority of the feldspar grains show alteration and fracturing.

Lithics are present in a small proportion as compared to other framework grains. The percentage of lithics ranges from 3 to 19 percent (Table 3). Chert is dominant lithic present in the sandstone of Dandot Formation (Fig. 5D). Among accessory minerals micas are most dominant in the studied sandstone and these are present as detrital constituents. Micas present include muscovite and biotite, muscovite is more abundant than biotite. Muscovite flakes show bending due to compaction (Fig. 5E). Opaque minerals include magnetite and hematite. Apart from these a few grains of glauconite are present (Fig. 5F).

Table 3: Normalized values of framework grains in sandstone of Dandot Formation

S.No	Quartz (%)	Feldspar (%)	Lithics (%)
01	69	27	04
02	67	30	03
03	71	25	04
04	62	19	19
05	65	29	06
06	38	54	08
07	71	23	06
08	73	23	04
09	65	24	11

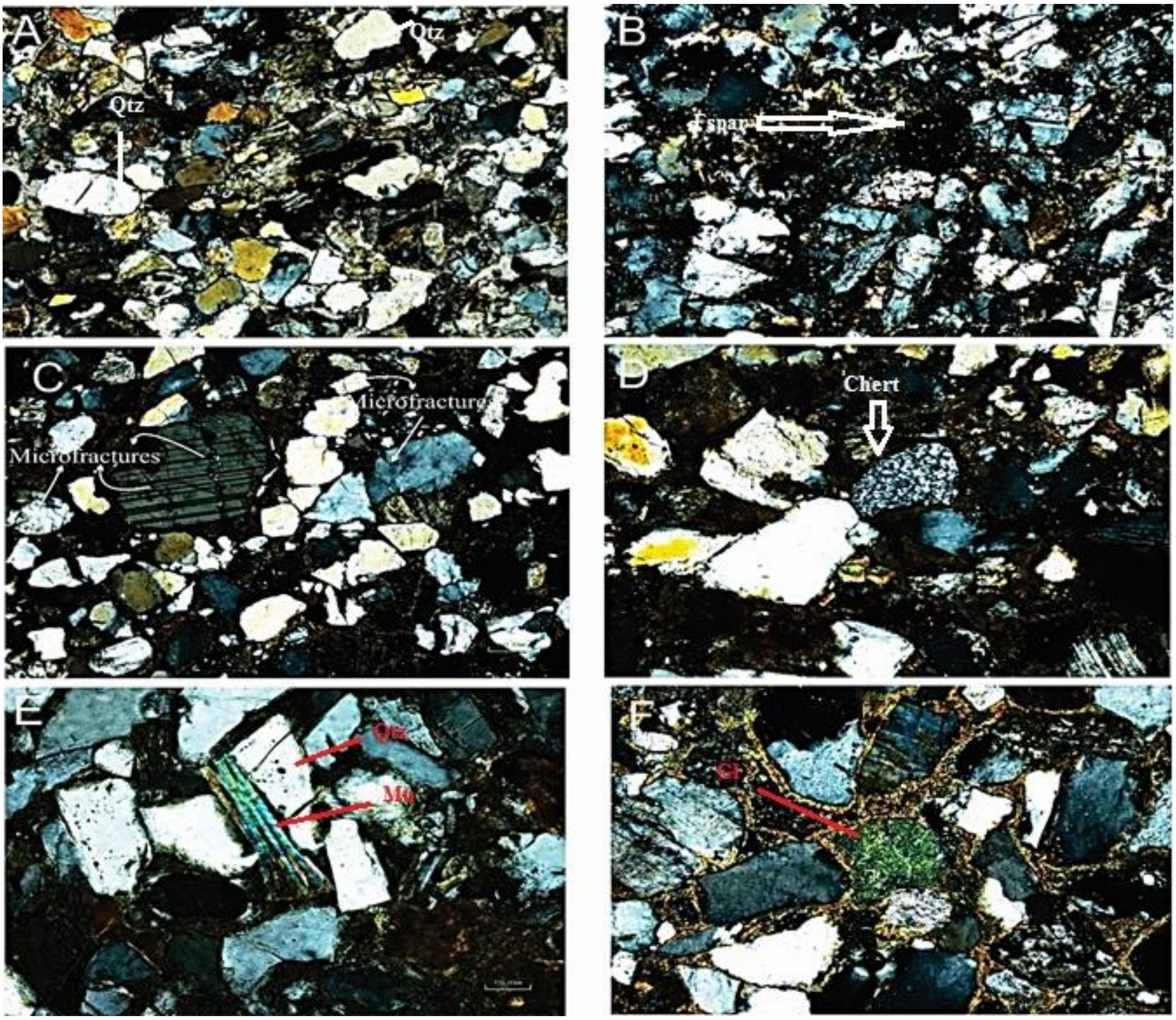

Fig. 5: Photomicrograph A) showing quartz (Qtz) grains, (B) showing highly altered feldspar (Fspar), (C) showing a grain of plagioclase and microfractures in grains (D) chert grain, (E) grain of a Muscovite (green) and a fractured quartz grain to the right of Muscovite (Mu), (F) grain of glauconite (Gl) (green) and ferruginous cementing material between the grains. All photomicrographs are in XPL.

3.3. Sandstone Classification

There are several triangular classification schemes exist with end members of quartz (Q), feldspar (F) and rock-fragments (RF). However, [13] classification was followed. The triangular classification indicates that the sandstone of Dandot Formation is arkose (Fig. 6).

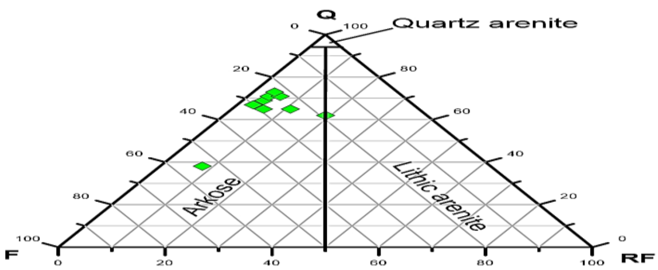

Fig. 6: Classification of studied sandstone samples following [13].

4. Mechanical Properties

4.1. Results and discussion

The most important and vital scope in rock mechanics is measuring and determination of rock properties and behavior by using the suggested testing methods, procedures and specifications. The engineering characteristics of rocks include such as its strength, mode of deformation and failure and modulus of elasticity. UCS is considered as the most striking property among all the mechanical properties. Three to five UCS determinations are recommended to achieve statistical significance of the results [14]. As discussed earlier three core samples of sandstone of Dandot Formation were obtained through drilling of bulk samples. UCS and UTS tests were performed on these samples and the resulting values are given in Table 4 and 5 respectively.

Table 4: Details of UCS test results of the studied samples.

Sample		Core (length)			Core (Diameter)			Area	Load	Strength
S.No	Type	mm	m	Inches	mm	m	Inches	m^2	KN	MPa
01	S1	304.8	0.304	12	152.4	0.152	6	0.0232	304	12.91
02	S2	304.8	0.304	12	152.4	0.152	6	0.0232	300	12.48
03	S3	304.8	0.304	12	152.4	0.152	6	0.0232	290	13.09

Table 5: Details of UTS test results of the studied samples.

Sample		Cube (Thickness)			Disc (Diameter)			Load	Strength
S.No	Type	mm	m	Inches	mm	m	Inches	KN	MPa
01	S1	25.4	0.0254	1	50.8	0.0508	2	5	3.87
02	S2	25.4	0.0254	1	50.8	0.0508	2	4	3.10
03	S3	25.4	0.0254	1	50.8	0.0508	2	3	2.32

Table 6: Material grading based on Unconfined Compressive Strength [8].

Geological Society (Anon, 1977)		IAEG (Anon, 1979)		ISRM (Anon,1981)	
Term	UCS (MPa)	Term	UCS (MPa)	Term	UCS (MPa)
Very Weak	<1.25	Weak	<15	Very low	< 6
Weak	1.25-5.00	Moderately Strong	15 - 50	Low	6 – 10
Moderately Weak	5.00-12.50	Strong	50 – 120	Moderate	20 - 60
Moderately Strong	12.50-50	Very Strong	120 – 230	High	60 – 200
Strong	50-100	Extremely Strong	Over 230	Very High	Over 200
Very Strong	100-200				
Extremely Strong	Over 200				

According to [15], UCS of rocks is eight times their UTS. Nevertheless, [16] suggested the ratio between UCS and UTS to be 10:1. But this is not the case in the present study. The UCS is 4 to 6 times greater than UTS. Similar results have also been obtained by [9, 17]. According to them the lower value of UCS to UTS ratio could be either of two reasons (i) the value of UCS is underestimated or (ii) UTS value is overestimated. In Table 6 the materials/rocks are specified according to their UCS values (see for detail) [8].

In the present research UCS values of the sandstone samples reveals that these rocks lie in the category of very weak to weak following [18] and Anon [19] respectively. The average values of cohesion and angle of internal friction of the Sandstone from Dandot Formation are 6.4MPa and 38º respectively. Specific gravity and water absorption are also calculated for the respective sandstone unit. Values are given in the following Table 7.

Table 7: Comparison of UCS, Specific gravity and Water Absorption.

Sample	UCS (MPa)	Specific Gravity	Water Absorption (%)
S1	12.91	2.02	11.91
S2	12.48	2.11	14.43
S3	13.09	1.81	9.25

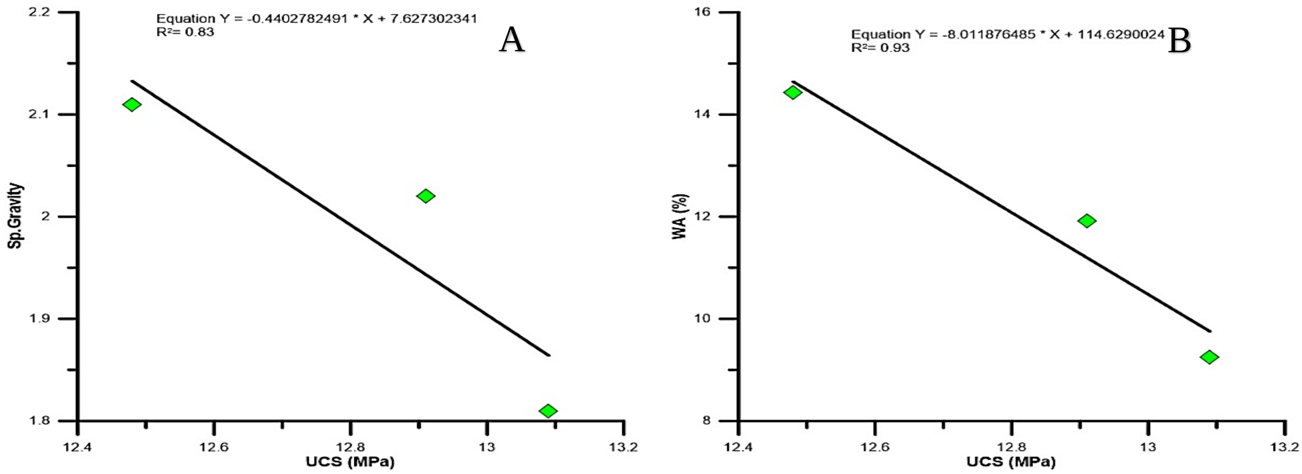

Fig. 7: A and B Showing Inverse relation of Specific gravity and water absorption with UCS.

UCS value is very low and reasons are i) the type and most importantly the amount of cementing material (see for detail) [8] and ii) most of the feldspar grains show alteration to sericite and kaolinite. Rocks having silica as cementing material are the strongest followed by calcite and ferruginous and with clayey binding material are the weakest [20]. On the other hand, a positive relationship has been observed between uniaxial compressive strength and percent cement/ matrix [21, 22]. In the current investigation the low amount of cement (less than 15%) and type of cement i-e ferruginous and presence of sericite and kaolinite (clay minerals are highly porous) shows high water absorption leads to the reduction in strength of sandstone of Dandot Formation. Apart from this, microfracturing in grains and nature of contacts of grains (long and tangential) also play a vital role in decreasing the UCS of the respective sandstone. Microfracturing results due to proximity of study area to the Salt Range Thrust. In [23] Blyth and DeFreitas proposed that rocks with specific gravity $\geq$ 2.55 are appropriate for heavy construction works. In the present case it is low and show inverse relation with UCS (Fig. 7A). On the other hand, water absorption values are also very high and depicts negative relation with the UCS (Fig. 7B).

5. Conclusions

Following are the main conclusions of this work.

i. Sandstone unit from Dandot Formation is classified as Arkose and is regarded as sub-mature both mineralogically and texturally.

ii. Grains of sandstone of Dandot Formation ranges from very fine to medium size and moderate to well sorted.

iii. The nature of grains contacts are tangential and long while, Ferruginous material acting as cement.

iv. Due to very low UCS values, low specific gravity and high water absorption values it is concluded that sandstone of the respective formation is not even suitable for small construction purposes rather than being used in heavy construction works.

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