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The Impact of Mineralogical Characteristics on the Physicomechanical Properties of Serpentinite from Prang Ghar, Mohmand District, Pakistan

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Abstract: The serpentinite samples of the Prang Ghar Mohmand Agency were analysed petrographically and physicomechanically to assess their potential as dimension stone and aggregate material. These rocks are prominently exposed along the suture zone between the Indian Plate and the Kohistan Island Arc, known as the Main Mantle Thrust Zone (MMTZ). On fresh surfaces, the serpentinite ranges in color from light green to dark green, while weathered surfaces appear yellowish green. Petrographically, the serpentinite is fine- to medium-grained and consists of serpentine, actinolite, talc, and magnesite, along with ore minerals like magnetite and chromite in varying amounts. The serpentinite can be categorized into four types: serpentinite, talc-serpentinite, actinolite-serpentinite, and chromite-bearing serpentinite. The physicomechanical properties were assessed through a series of tests, which were then compared to ASTM standards to evaluate their quality. These tests included unconfined compressive strength (UCS) (46.0–49.94 MPa), cube test (198.56–234.34 MPa), flexural test (8.20–13.28 MPa), specific gravity (2.58 mg/cm³), and soundness (3.35%). The results indicate that the serpentinite exhibits properties that meet international standards for use as dimension stone and coarse aggregate. Based on these findings, it can be concluded that the Prang Ghar serpentinite is a viable material for construction applications, such as flooring and exterior wall cladding. This study emphasizes the strong correlation between the mineral composition of serpentinite and their physicomechanical properties. An increase in talc content is associated with reduced strength, along with higher water absorption and porosity. Additionally, the presence of actinolite and ore minerals also influences the physicomechanical behavior of serpentinite. This study confirms the necessity of petrographic analysis before using rock as an engineering material.

Keywords: Dimension stone, Prang Ghar, serpentinite, petrography, physicomechanical properties.

Introduction

Dimension stone is generally defined as a natural rock quarried for the purpose of cutting and shaping to a specific size for its use as building and decorative stone (Barton, 1968; Dolley, 2004). According to US Bureau of Mines (USBM), the dimension stone is the naturally occurring rock which is cut, shaped or selected for use in blocks, slabs, sheets or other construction units of specialized shapes and sizes (Ashmole and Motloung, 2008). Various rock types used as a dimension stone include limestone, granite, gabbro, slates, dolerites, marble and serpentinite etc. Pakistan has ample deposits of dimension stone like marble, granites, serpentinite, gabbro, dolerites, slates and limestone. (Mehdi, 2006). The serpentinite is gaining its popularity demand in local and international markets because of its beautiful colour and easy shaping. It has been used since the ancient Greek in Italian construction industry. In Pakistan, Wali Swat heritage and in more modern times, it has been used for making decorative items like columns, statues, and flooring, as well as for structural purposes (Meierding, 2005). Serpentinite has been named as Vermont Verde Antique (US) and Verdi Pirineos (Spain), Emerald Green (India). One reason for its popularity is its relative durability and smooth texture, which develops an attractive sheen when polished. The Prang Ghar study area is located in the Mohmand District of Pakistan (Fig. 1). Geologically, it lies along the northern edge of the Peshawar Basin and falls within the western segment of the Main Mantle Thrust (MMT) zone, which is characterized as tectonic melange (Hussain et al., 1984). Indian Plate

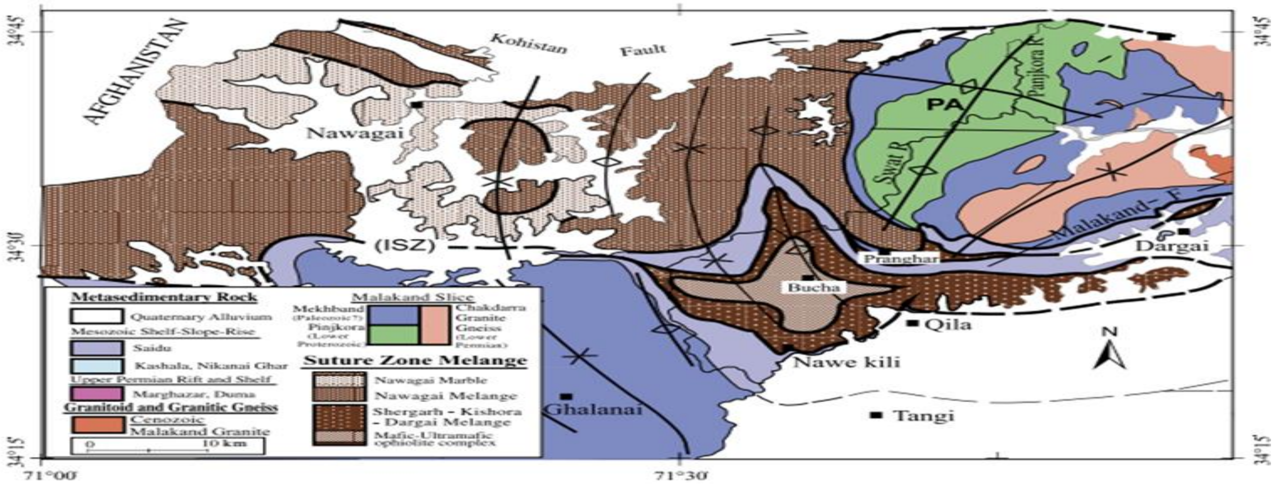

Fig. 1 Geological map showing the study area (after Dipietro et al., 2008).

exists to the south of the MMTZ/study area while the Kohistan Island Arc (KIA) to the north. The serpentinite rocks are well exposed in the Prang Ghar area which is quarried at several localities for its use as dimension stone and aggregate.

It is known that variations occur in the physio-mechanical properties of rocks due to change in texture, structure, mineralogical and elemental compositions. Therefore, an adequate analysis is necessary before the use of rocks in the engineering works which may prevent many disasters and hence can save human lives and their properties (Dahal, 2019; Richard et al., 2022). To characterize serpentinite as a dimension stone (structural and monumental uses), both its physicomechanical properties and mineralogical composition must be thoroughly studied as no research work has been carried out on the rocks of this area. The aim of this study is to analyse the petrographic and physicomechanical properties of serpentinite exposed in Prang Ghar area to asses their suitability as dimension stone and coarse aggregate material.

Geology and Tectonics of the Study Area

North Pakistan represents an excellent collisional tectonic model resulted from the episodic collision of the Eurasian Plate, Kohistan Island Arch (KIA) and Indian Plate. In the first episode the Kohistan Island Arc (KIA) collided with Eurasian Plate during the Late Cretaceous time and formed a collisional zone known as Main Karakoram Thrust Zone (MKTZ) (Treloar et al., 1989).

In the second episode, the Indian Plate collided with the KIA in the Palaeocene-Eocene, thus forming the collisional boundary known as Main Mantle Thrust Zone (MMTZ) (Tahirkheli, 1979). This collision was accompanied by large-scale emplacement of ophiolites sequences along both MKTZ and MMTZ ((Tahirkheli, 1979). The MMTZ ophiolites and melanges are metamorphosed and sandwich between the KIA and Indian Plate (Baig et al., 1989; DiPietro et al., 2000). In this zone the rocks are grouped into three fault-bounded melanges named ophiolitic, blueschist and greenschist.

The study area is part of lower Mohmand District located in this melange zone between KIA and Indian plate which are composed of mafic-ultramafic rocks, metasediments of calacareous, silicious and pelitic nature, subordinate amount of pillow basalts and greenstones of volcanic nature (Hussain et al., 1984). From north to south, the Prang Ghar is divided in to three zones: 1) Northern, 2) Central zone and 3) Southern zone (Hussain et al., 1984). The northern zone is dominated by ophiolitic sequence like ultramafic, gabbro, metavolcanics, mafic pillow basalts, greenschists and quartzites/metacherts (Fig. 2). In the central zone occur broken blocks of greenstones, metasediements and grayish-green to dark green colour ultramafic rocks. The southern zone is dominated by grey-greenish greenschist with a number of quartz veins and talc- carbonate schist (soapstone). Dominant lithologies of Prang Ghar include ultramafics (peridotite, serpentinite), talc schist, green schist, and quartzite rocks showing thin bands of manganese ores like braunite (Anjum, 2012; Fig. 2).

Materials and Methods

A total of six bulk samples of serpentinite were collected from the area of Prang Ghar Mohmand District. For petrographic examination, 12 thin sections were prepared from the collected samples. To know the physicomechanical properties, the core samples were obtained from the samples as per ASTM-D7012 specifications. Six cubes, each of one cubic inch, were prepared from six bulk samples for cube test (ISO 14579. Six rectangular samples were prepared from the bulk samples for flexural test. One representative sample was cut in to rectangular form for 3-point bending test. Twelve thin sections were prepared from the rock samples for petrographic analysis using the standard techniques. Finally, coarse aggregates were prepared for Los Angles test

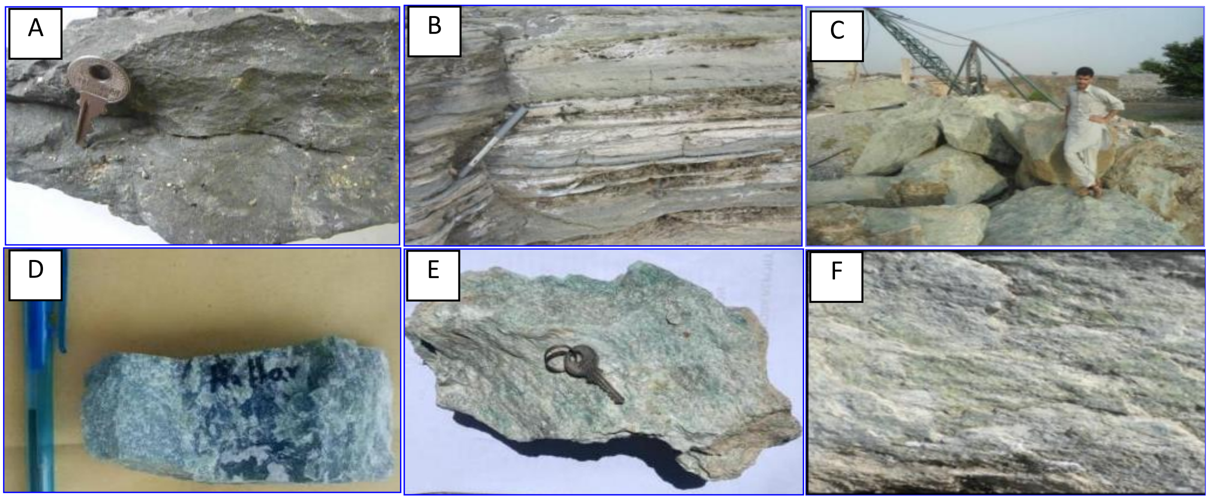

Fig. 2. Showing field and hand-specimen photographs of Prang Ghar Mohmand District. (A-F); peridotite (A), greenschist (B), and serpentinite (C-F).

from the left over material. Unconfined compression strength (UCS) test is widely performed though Universal Testing Machine (UTM) for the engineering classification of rocks in accordance with the American Society for Testing and Materials (ASTM, 2002). The principle of cube tests is similar as unconfined compression strength (UCS) test which was performed to find out the strength at per square inch area of rock by applying load of UTM. Moh's hardness scale is used here to find out the relative hardness of the studied serpentinite.

The flexural test determines rocks capability to bear load (ASTM C 880) and estimated for rocks used as dimension stone for building facades and flooring material. This test gives the strength of a rock to bear maximum load in a curtain-wall system. Los Angeles Abrasion (ASTM C 131-03) investigates the wear and tear of the coarse aggregate of rocks. For the determination of porosity **(**ASTM C 97), the saturation method has been used (Logan and Harrison, 1993). Specific gravity test (ASTM C 12788), density (ASTM C97) and soundness tests (ASTM C-88, 1999) were also determined.

Results and Discussion

Petrography

The petrographic details are summarized in Figures 1 to 3 and Table 1. The mineralogical composition of serpentinite of Prang Ghar are: a) serpentine, b) actinolite, c) ore minerals, d) talc and e) magnesite. Serpentinite shows variable amount of serpentine in different samples (55 — 85%; Fig. 3). It shows greyish colour in plane light with characteristic low order interference colour, while texturally it ranges from microcrystalline to mesocrystalline (Fig. 3A-C).

In some samples pseudomorphic grains (bastite), whose original mineral is pyroxene, can be seen under polarized microscope (Fig. 3b). In some samples the serpentinization is more extensive and therefore no pseudomorphic texture after original minerals can be seen under the polarized microscope (Fig. 3a). These serpentinites are generally considered to have developed by direct hydration of ultramafic complexes (Coleman, 1979). Lack of pseudomorphs after primary minerals within the serpentinite reflect intense hydration activity in the study area as compared to the rocks lying to further north. Serpentine occurs as chrysotile needle/fibrous shape of light-grey color or as fine-grained minerals constituting the rock matrix (Fig. 3a). Serpentine generally occurs either inter grown with talc (Fig. 3c), and as separate patches or veinlets (Fig. 3d) or in the form of inclusions in other minerals as in pseudomorph with amphibole and pyroxene (Fig. 3b). Actinolite is the second abundant mineral with a range of 5 to 25%. This needle shape mineral which commonly occurs in disseminated or in pseudomorphic forms in the rock (Figs. 3b, c). It is one of the parent minerals which transforms to serpentine.

Talc is the fourth most abundant mineral in the serpentinite which ranges from 4—19% by volume. It is generally formed by alteration of serpentine. It occurs mostly as needle shape grains and at some places in the form of matrix. It shows high order interference colors and shows parallel extinction (Fig. 3E). Magnesite is also present with a modal abundance of 2 to 10%. It occurs as coarse grains in disseminated form while exhibiting a distinct low order interference colour, parallel extinction and also cleavages (Fig. 3H). Ore minerals are in the range of 5 — 25% as the third abundant mineral in the petrographic extinction. These opaque minerals show

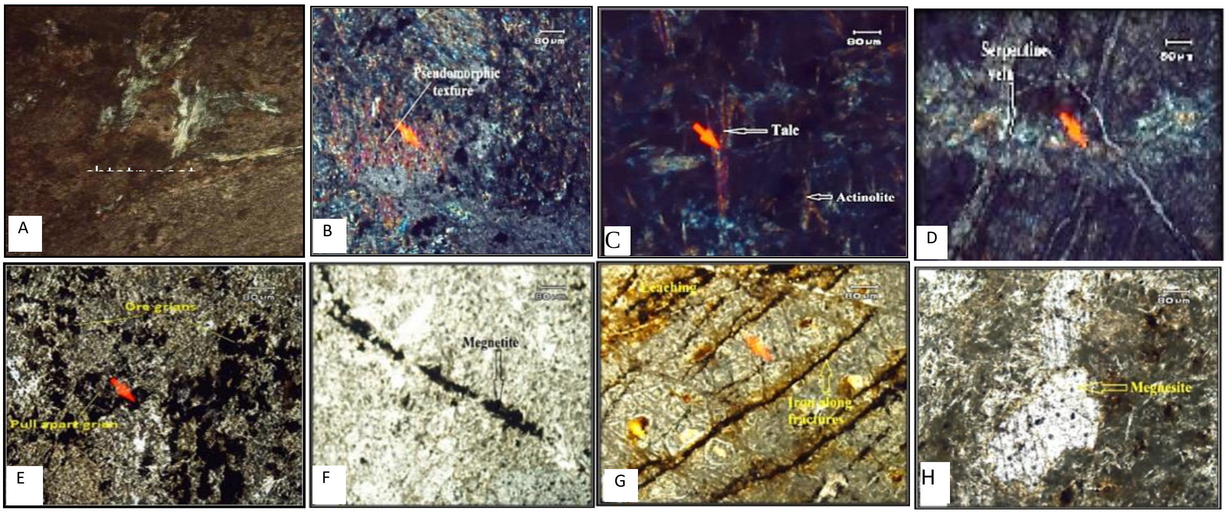

Fig. 3 Microphotographs at (XPL, Mag: 4x) (A) Serpentinite grains with chrysotile, (B) Pseudomorphic grains in serpentinite, (C) Talc in serpentine, (D Serpentine vein, (E) Chromite grains in disseminated form, (F) Magnetite in the form of trails or veins, (G) Iron along fractures shows leaching at surrounding, (H) Carbonate (Megnesite) grains.

Table 1. Modal mineralogical details of serpentinite.

Sample no	Serpentine %	Actinolite %	Talc %	Carbonate (Megnesite) %	Ore minerals %
1	57	05	19	10	09
2	54	21	03	10	12
3	63	09	19	01	08
4	60	25	5	05	05
5	55	10	6	04	25
6	85	06	4	02	03
Total range	54－85	5－ 25	4－19	2 -10	3 － 25

blackish and dark brownish color which seems magnetite and chromite grains respectively (Fig. 3E).

Chromite usually occurs as medium sized disseminated in serpentine (Fig. 3E). Chromite grains commonly exhibit pulled-apart structure and range in color from brownish-black (opaque) in the middle to yellow-brown at the peripheries (translucent) and along the cracks, which reflect release of iron and formation of magnetite and limonite with yellowish brown to orange color (Fig. 3F).

Physicomechanical Properties

Table 2 describes the summary of the calculated physicomechanical properties of serpentinite of Prang Ghar Mohmand District. Physicomechanical properties of all six samples show less variation. The water absorption for all six sample are 1.65－1.73%, the porosity is 4.35－4.49%, the specific gravity is 2.58-1.73 and density is 2.58-2.72g/cm^3, soundness test value is 3.12－3.39 and Moh's hardness is 4.5-5.

The compressive strength (UCS) ranges between 46.1-49.98 Mpa. The range of cube test is 211.29238.3 Mpa, whereas the flexural strength is 12.04 13.28 Mpa and Los Angeles Abrasion resistance varies between 12.13-13.18. The data show that for sample 1 and 3, the UTS, UCS, and L.A value is less as compared to other samples (Table 2).

This study investigates the serpentinite from quarries at Prang Ghar, focusing on petrographic and physico-mechanical properties. The mineralogical and physicomechanical data have been used to compare and correlate with one another to get some new findings and conclusions. These calculated data are also compared with the Bell (2007) and Quack (2000; Table 3) for classification to know about the category of strength. Variation is observed in mineralogical compositions and geo-mechanical properties among the analyzed samples (Tables 1, 2). However, these values i.e, unconfined compressive strength (UCS), cube test, flexure test, are in the range of moderate strength categories and hence within the suitable range required for a rock to be

Table 2. Showing the overall summary of calculated values of Prang Ghar serpentenites.

Sample no.	**1**	**2**	**3**	**4**	**5**	**6**
Water Absorption	1.73	1.66	1.75	1.65	1.63	1.68
Porosity %	4.49	4.36	4.47	4.35	4.35	4.37
Density /Specific gravity (g/cm^3)	2.62	2.62	2.63	2.58	2.72	2.58
UCS strength (Mpa)	46.1	48.01	46.15	48.23	49.98	47.66
Cube tests strength (Mpa)	200.34	225.98	211.29	229.4	238.3	227.28
Flexural Strength (Mpa)	11.11	12.28	11.04	12.2	12.89	11.33
Soundness test	3.12	3.35	3.11	3.35	3.39	3.35

Table 2. Comparison between Serpentinites of Macael (Almeria, south of Spain) (Navarro.,2015).

Rock Type	Water absorption (wt %)	density (g/cm^3)	UCS strength (MPa)	Flexural strength (Mpa)	Soundness test Loss %	Hardness	Abrasion resistance
						Moh’s	L.A
Marble (ASTM)	0.2	2.56	52	07	10	2 - 4	10
Studied Serpentinite	1.7	2.58	46.01-49.94	8.2-13.28	3.35	4.5-5	12.13-12.98

Table 4. Showing Petrographic comparison of Macael and Prang Ghar Serpentinite**.**

Name Sample	**Serpentine %**	**Talc %**	**Actinolite %**	**Calcite %**	**Magnesite %**	**Ore minerals %**
Serpentinite of Verde Macael 1	88-89	-	-	<1	-	11-12
Serpentinite of Verde Macael 2	82 - 100	<1-45	-	30-65	-	<1-15
Serpentinite of Current study	54-85	4-19	5- 25	-	2 -10	3 - 25

used as dimension stone and aggregate (Table 3; Bell, 2007). Similarly the water absorption, density/specific gravity, soundness, relative hardness and LA values are comparable with those of marbleand limestone (Table 3; Anjum et al., 2018). The types and proportions of minerals present in a rock determine its physical, chemical, and mechanical characteristics (Rigopoulos et al., 2012). In order to see the effects of mineralogy on physicomechanical properties of rocks, different plots are constructed (Fig. 4). The relationship suggests that as the concentration of talc increases in different rock samples, the engineering properties such as uniaxial compressive strength (UCS), cube test strength, and flexural strength decrease (Fig 4). This is an important observation, as it shows that the amount of talc controls the mechanical properties of the rock. Talc is a very soft mineral, with a low Moh’s hardness (1 out of 10). This softness affects the overall strength of the rock. Talc acts as a "lubricant" between mineral grains in the rock, making the rock more susceptible to deformation and failure under stress.

On the other hand, the higher amounts of chromite (25% by volume) in sample 5 correlate with higher strength, this could point to chromite being a key factor in improving mechanical performance. Sample No. 4 is also showing higher values in terms of UCS, Cube test and flexture tests as compared to sample 6

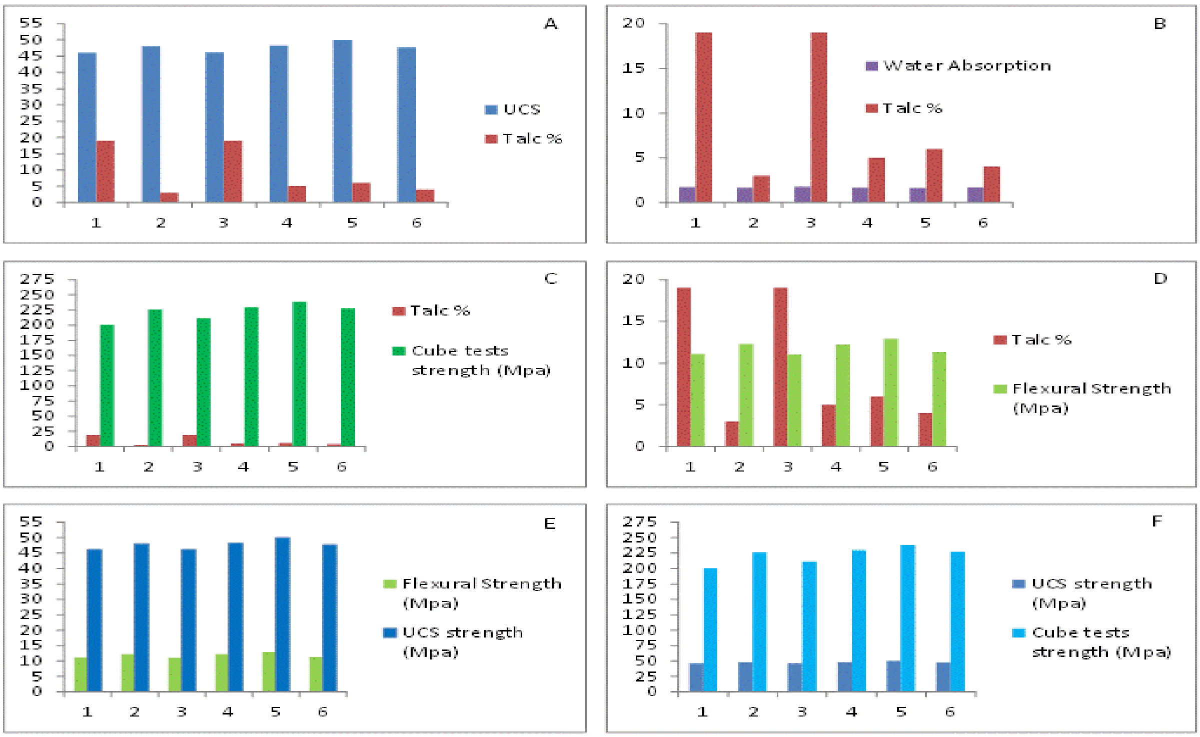

Fig. 4 Showing the mutual relationship of mineralogy and physicomechanical properties; Talc and UCS (A),Talc with Cube test strength and Flexure strength (B, C respectively), Talc and water absorption (D), UCS with flexure strength and Cube test strength and (E, F respectively).

which could be attributed to the higher amount of actinolite (Table 2, Fig 3). The weak bonding between the sheets in talc allows water molecules to easily enter between these layers. This gives talc its ability to absorb and retain moisture. This increase in the water absorption and porosity in sample 1 and 3 is because of the increasing amount of talc (Table 3, Fig. 4).

Table 4 shows the petrographic and physicomechanical properties comparison of Macael serpentinite with Prang Ghar serpentinite. Verde Macael 1 serpentinite is mainly consisting of serpentine, talc and ore minerals while Verde Macael 2 serpentinites mainly consists of serpentine, talc, calcite, ores minerals. Whereas the studied serpentinite are consisting of serpentine, talc, actinolite, epidote and ores minerals.

Conclusion

The Prang Ghar serpentinites contain less percentage of serpentine and more concentration of talc and ores percentage when compared to the Macael 1 and Verde Macael 2 serpentinite. The calcite is absent in Prang Ghar serpentinite while actinolite is lacking in the Verde Macael 1 and Verde Macael 2 serpentinite. The density, porosity, water absorption and UCS of Prang Ghar serpentinite are lower than those of Macael serpentinite (Table 4). Therefore, the Macael serpentinite are more in strength and other physicomechanical properties as compared to Prang Ghar serpentinite. This could be attributed to variation in mineral contents and textures. The Prang Ghar serpentinite comprises varying proportions of serpentine, talc, actinolite, magnesite, and ore minerals. Based on its mineral composition, it can be classified into serpentinite, talc-serpentinite, actinolite-serpentinite, and chromite-bearing serpentinite.

Results from soundness, Los Angeles abrasion, specific gravity, density, cube strength, and flexural strength tests fall within the permissible limits for use as dimension stone and construction aggregate, indicating that the serpentinite has moderate strength. Similarly, water absorption and porosity values also lie within acceptable limits. The study concludes that the mineralogical composition of serpentinite significantly affects its physical and mechanical properties. In particular, talc plays a key role in determining the suitability of serpentinite for engineering applications. From the detailed field observations, petrographic and physico-mechanical characteristics of the selected rocks of Prang Ghar area it is suggested that the Prang Ghar serpentinite is not suitable for its use in mega construction projects. However, their use in small road projects (aggregates), and in tile making is recommended. The properties are almost conformable with marble therefore, it can also be used as dimension stone on the exterior and interior of the walls, and also for flooring, not used for heavy loads such as vehicles.

References

American Society for Testing and Materials C-131, (2003). Standard test method for resistance to degradation of small-size coarse aggregate by abrasion and impact in the Los Angles machine. American Society for Testing and Materials, Philadelphia, Pa. USA, 1-4.

American Society for Testing and Materials C 127, (2001). Standard test method for specific gravity and absorption of coarse aggregate, Philadelphia, PA.

American Society for Testing and Materials D2938-95, (2002). Standard test method for unconfined compressive strength of intact rock core specimens.

American Society for Testing and Materials C97/C97M-18, (2015). Standard test methods for absorption and bulk specific gravity of dimension stone.

American Society for Testing and Materials Designation: C 880-98, (1998). Standard test method for flexural strength of dimension stone, American Society for Testing and Materials.

Anjum, M. N., Shah, M. T., Arif, M. (2012). Mineralogy, geochemistry and genesis of manganese ores of Pranghar area, Mohmand Agency, FATA, Pakistan. *Journal of Himalayan Earth Science*, **45** (2), p 26.

Anjum, M. N., Ali, N., Rehman, Z., Ghayas, M., Ahmad, W. (2018). Rock aggregate potential of the limestone units the Khyber Formation, Khyber Ranges, Pakistan. *Int. J. Econ. Environ. Geol.*, **9** (4), 26-33.

Ashmole, I., Motloung, M. (2008). Dimension stone: The latest trends in exploration and production technology. Proceedings of International Conference on Surface Mining and Metallurgy Johannesburg, South Africa, 35-70.

Baig, M. S. (1990). Structure and geochronology of Pre-Himalayan and Himalayan orogenic events in the Northwest Himalaya, Pakistan, with special reference to the Besham area.

ASTM, D Test, Water Absorption, Test, Compressive Strength, Test, Abrasion Resistance (1950) American society for testing and materials. American Association of State Highway and Transportation Officials-AASHTO Standards, United States.

Dahal, R. K. (2019). South Asian perspectives in understanding role of engineering geology for geodisaster management. In: Shakoor, A., Cato, K. (eds.) IAEG/AEG Annual Meeting Proceedings, San Francisco, California, 6. Springer, Cham. https://doi.org/10.1007/978-3-319-93142-5_4.

DiPietro, J. A., Hussain, A., Ahmad, I., Khan, M. A. (2000).The main mantle thrust in Pakistan: its character and extent. *Geological Society, London, Special Publications*, **170**(1), 375-393.

DiPietro, J. A., Ahmad, I., Hussain, A. (2008). Cenozoic kinematic history of the Kohistan fault in the Pakistan Himalaya. *Geological Society of America Bulletin*, **120** (11-12), 1428-1440.

Dolley, T. P. (2002). Stone, Dimension: US Geological Survey Minerals Yearbook, **I**—Metals and Minerals. US Geological Survey, Reston, 86 pages.

Harrison, D. J., Inglethorpe, S. D. J., Mitchell, C. J. (1993). Industrial minerals potential of Fiji.

Hussain, S. S., Khan, T., Dawood, H., Khan, I. (1984). A note on Kot-Prang Ghar melange and associated mineral occurrences. *Geological Bulletin University of Peshawar*, **17,** 61-68.

Hussain, S. S. (2005). PhD Thesis, University of Punjab, Lahore, Pakistan.

ISRM (1981). Rock characterization, testing and monitoring. Pergamon Press Oxford, 221 pages.

Mehdi, A., Chaudhry, M. A. (2006). Diagnostic study marble granite cluster. Rawalpindi Pakistan. UNIDO-SMEDA Cluster Development Programme: Rawalpindi, Pakistan.

Meierding, T. C. (2005). Weathering of serpentine stone buildings in the Philadelphia, Pennsylvania, region: A geographic approach related to acidic deposition. Special papers-geological society of America, 390, 17.

Barton, W. R. (1968). Dimension stone: United States Bureau of Mines Information Circular.

Bell, F. G. (2007). Engineering Geology: Elsevier.

Rigopoulos, I., Tsikouras, B., Pomonis, P. Hatzipanagiotou, K. (2012). The impact of petrographic characteristics on the engineering properties of ultrabasic rocks from northern and central Greece. *Quarterly Journal of Engineering Geology and Hydrogeology*, **45** (4), 423-433.

Richard, H. L., Jennifer, H., Joel C., G., Marcus, D., Cheryl, L., Peter, I. (2022).The role of engineering geology in delivering the United Nations Sustainable Development Goals. *Quarterly Journal of Engineering Geology and Hydrogeology*, **55** (3), qjegh2021–127. doi: https://doi.org/10.1144/qjegh2021-127

Tahirkheli, R. A. Khan. (1979). The India-Eurasia suture zone in northern Pakistan: Synthesis and interpretation of recent data at plate scale. Geodynamics of Pakistan, 125-130.

Treloar, P. J., Petterson, M. G., Jan, M. Q., Sullivan, M. A. (1996). A re-evaluation of the stratigraphy and evolution of the Kohistan arc sequence, Pakistan Himalaya: implications for magmatic and tectonic arc-building processes. *Journal of the Geological Society*, **153**(5), 681-693.