

REVIEW ARTICLE

EVALUATION OF GEOTECHNICAL PROPERTIES AND PETROGRAPHIC CHARACTERISTICS OF SANDSTONE, BAGH AREA, AZAD JAMMU AND KASHMIR, PAKISTAN

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ABSTRACT

Sandstones are abundant in the regions of Azad Jammu and Kashmir in northeastern Pakistan. However, physio-mechanical data for project planning and construction of these sandstones, which serve as aggregates and foundations for a variety of infrastructures, are lacking. This research aims to investigate the petrographic and physio-mechanical characteristics of Murree and Kamlial Formation sandstones in the Rawalpindi group. The physio-mechanical parameters included specific gravity, water absorption, unconfined compressive strength (UCS), slake durability, Ultrasonic pulse velocity (UPV), and Brazilian. The findings suggest that the sandstone of the Murree and Kamlial formations can be classified as construction-grade rocks. A comprehensive analysis of physico-mechanical observations of these sandstones shows a statistically significant correlation with point load index, Brazilian tensile strength, and UPV in a saturated condition against unconfined compression strength (UCS). Whereas the specific gravity, water absorption, slake durability index, and UPV in dry conditions found no statistically significant correlation against UCS. By rigorous petrographic research, the texture of quartz %, mineralogy and mineral alteration, the existence of micro-fractures, and mineral size distribution all contribute to the total strength qualities of these sandstones. To comprehend the suitability of Muree and Kamlial Formation sandstones, physio-mechanical characteristics were then correlated with the sequence (Murree sandstone) exposed at the Jena Kor village in Peshawar Basin. Based on the results, the sandstones of the Murree and Kamlial Formations in the study area are found appropriate for construction.

KEYWORDS

Sandstone, Kashmir Basin, Physio-mechanical Properties, Correlation, Mineralogy

1. INTRODUCTION

The geotechnical study is a crucial initiative for enhancing the quality, durability, and safety of heavy and lightweight structures such as dams, highway tunnels, and bridges (Rehman et al., 2020). The features of construction materials differ from rock to rock and are highly impacted by the formation of rocks and the conditions that prevailed during rock formation and metamorphism (Carvalho et al., 2013). Various tectonic phases have an impact on lithological characteristics, mineral compositions, strength properties, and how rocks react to both chemical and physical weathering (Mustafa et al., 2015, 2016; Yarahmadi et al., 2018). Sandstone has long been considered amongst the most popular dimension stones and building materials. Effective structural and dimension stone utilization necessitates a thorough understanding of their strength qualities. In engineering courses, evaluating the geotechnical properties of construction materials such as sandstone is crucial.

In the literature, the physio-mechanical behavior of rocks used as building and dimension stones is widely researched. (Menningen et al., 2022; Mezza et al., 2022; Pötzl et al., 2022; Siedel and Siegesmund, 2014;

Siegesmund and Snethlage, 2011). These qualities are influenced by a variety of causes, but the mechanical behavior of the rock is often the consequence of several influencing aspects such as petrography, mineralogy, shape and texture, erosion, permeability, and fractures (Goldscheider, 2008; Siedel and Siegesmund, 2014; Tercan and Ozcelik, 2006; Tuğrul and Zarif, 1999). Because rocks are used in buildings, the construction sector works to meet all physical and mechanical standards to ensure their acceptability (Siegesmund and Török, 2011; Sousa et al., 2016). Rocks' physical attributes are primarily dictated by their texturing, geological formations, petrological characteristics, and environmental factors. (De Vallejo and Ferrer, 2011)

Furthermore, petrographic features influence the geotechnical behavior of construction materials (Sajid et al., 2016; Vazquez et al., 2018). It is essential to comprehend the behavior of rocks by considering how it responds to various petrographical characteristics such as grain size, grain shape, orientation, and fractures. (Hyslop and Alborno-Parra, 2009; Ingham, 2005; Lindqvist et al., 2007; Nasser et al., 2005; Nasser and Mohanty, 2008; Ray et al., 2006; Rivas et al., 2000; Seo et al., 2002; Silva and Simão, 2009; Sousa, 2013; Sousa et al., 2005; Tham et al., 2003; Vasconcelos and Lourenço, 2009). The aforementioned petrographic

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properties are not often addressed in dimension stone categorization. The current study investigates these aspects as well to determine their influence on rock strength.

Furthermore, the petrographic examination must take into account certain environmental circumstances (Sousa, 2012). The mineralogical qualities of a rock reveal information about its mineralogical composition and origins. Additionally, they disclose details on durability and weather resistance (Jamshidi et al., 2013). Many researchers have investigated mechanical features and their relationship to mineral composition (Miskovsky et al., 2004; Torkan et al., 2016). However, the characteristics of the minerals that create rocks and their susceptibility to degradation may influence rock properties (Karaca and Onargan, 2008; Tiryaki and Dikmen, 2006; Woo et al., 2006).

The unconfined compression strength (UCS) of intact rock is widely used to determine its strength. (Zorlu et al., 2008). UCS is used to characterize and classify buildings and dimension stones based on their strength features (Nasiri et al., 2021). Petrographic parameters also influence UCS characteristics (Ündül, 2016). Brazilian and slake durability tests, and nondestructive test such as ultrasonic pulse velocity (UPV) is also useful in determining the strength of (Del Río et al., 2006; Rahman and Sarkar, 2022). Grain size, microfractures, orientation, and mineralogy all have an impact on UPV (del Río, 1982).The mechanical behavior of dimension stones is also influenced by other parameters, such as grain size distribution, and grain orientations (Eberhardt et al., 1999; Pfikryl, 2006; Sousa, 2013). Weather resistance and durability, porosity and weathering degree (Sims, 1991; Vasconcelos and Lourenço, 2009; Wong et al., 2006; Aydin and Basu, 2005; Hudec, 1998; Sousa, 2013; Yavuz et al., 2006). Because of mineral disintegration and the formation of micro-crakes, the porosity and degree of weathering have an adverse relationship with the mechanical properties of the rocks (Sousa, 2013; Steiger et al., 2011). Furthermore, visual characteristics contribute to the selection of accessible types (Eren and Bahali, 2005; Sousa, 2013).

Azad and Jammu Kashmir the northeastern part of Pakistan is abundant in construction materials and dimension stones. Sandstone is used to construct the Neelum Jhelum hydropower dam and several other commercial and governmental structures. In the tectonically active area of

Azad Jammu and Kashmir, several types of buildings and dimension stones are utilized to create infrastructure. This comprises roads, dwellings, educational institutions, hospitals, etc. However, prior comprehensive research on the strength characteristics of sandstone from various parts of Azad Jammu and Kashmir such as Murree and Kamliyal formations in the Bagh area was lacking.

Therefore, the physico-mechanical and petrographic characteristics of these construction materials have not been used to assess their quality. Consequently, the current study was carried out to establish the fundamental physio-mechanical analysis and petrographic characteristics of the rocks in the study area, and the current study's findings were compared to the sequence (Murree sandstone) exposed in the Jena Kor village in the Peshawar Basin, to comprehend the importance of sandstone rocks, correlate the physio-mechanical characteristics, and assess their quality for use as a building and dimensioning material. This research will also assist in the future establishment of new economic channels and substantial infrastructure development in the area, notably in the context of the China-Pakistan Economic Corridor (CPEC).

2. GEOLOGICAL SETTING

Bagh section is located in the Himalayan Mountain Belt in Pakistan's North East (NE). The Himalayan Mountain Range is the consequence of a tertiary collision between the Indian and Eurasian plates (Baig and Lawrence, 1987; Wadia, 1931). As a result of the Himalayan impact, the sedimentary rocks in the region have been folded, faulted, fractured, and joined. The active Muzaffarabad Fault, also known as the Himalayan Frontal Thrust, ran across Allai Kohistan, Balakot, Muzaffarabad, Bagh, Lasdana, Chrikot, and Poonch, as well as Indian-controlled Kashmir (Baig and Lawrence, 1987; Baig, 2006). The Muzaffarabad Fault spread into the Raikot Fault. The Muzaffarabad Fault places the Murree Formation on top of the Nagri Formation. The Muzaffarabad Fault was reactivated on October 8, 2005, during the Kashmir earthquake (Baig, 2006). A zone of active landslides, fractures, joints, and fissures, and fissures along the Muzaffarabad Fault allows radon to reach the surface. The geological map of the research region is shown in Figure 1(a), which was generated from the Geological Survey of Pakistan (GSP) 2004.

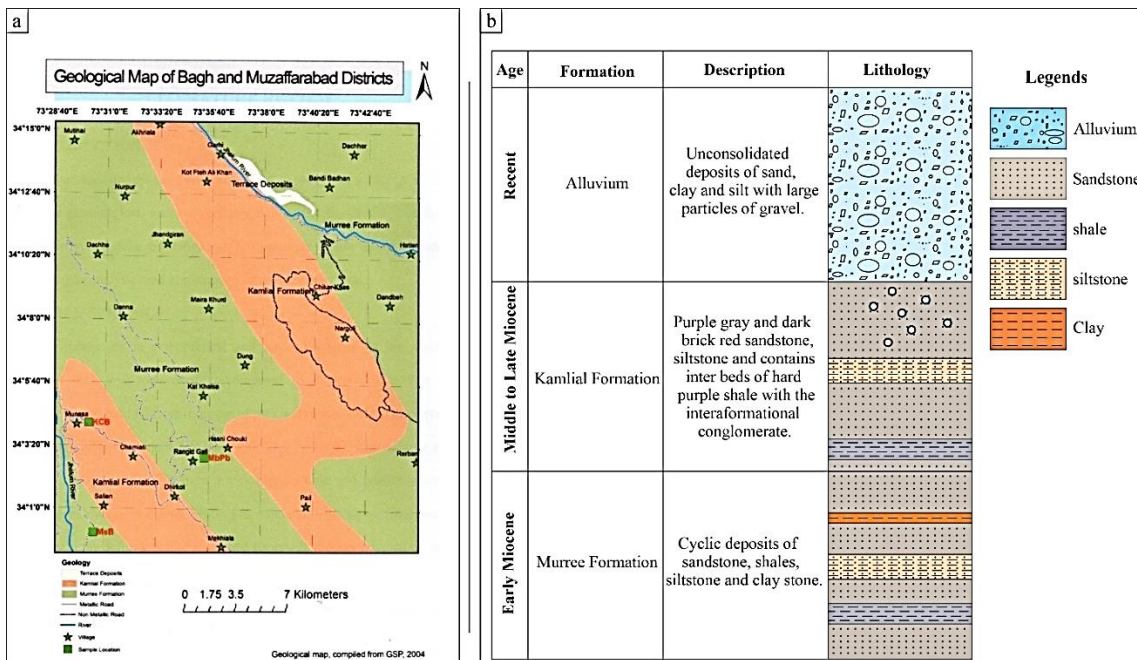


Figure 1: (a) shows the geological map of the study area, generated by the Geological Survey of Pakistan (GSP) 2004, (b) shows the Stratigraphic column of Miocene in Murree and Kamliyal formation of Rawalpindi Group.

The Murree Formation is a deep fluvial sequence of dark red and purple clay and red, brown to greenish-grey sandstone with subsequent intraformational conglomerate (Kazmi and Abbasi, 2008; Kazmi and Jan 1997; Shah, 2009). Sandstone is agglomerated with calcareous sandy conglomerate beds in certain areas (Khan et al., 2021). particularly in the lower Section of the Formation (Shah, 2009). The Murree Formation is exposed east of the Jhelum Fault and is only found in the axial zone of the Hazara Kashmir Syntaxis HKS. Medium to coarse-grained purple-grey and dark brick-red sandstone are interbedded with firm purple shale and yellow and purple intra-formational conglomerate in the Kamliyal Formation (IA, 2008). The Kamliyal Formation is categorized as sandstone

in 75 % of the Formation, siltstone in 20%, and intraformational conglomerate in 5%, according to (Kazmi and Abbasi, 2008). It frequently occurs at the base of massive sandstone formations and contains a lot of intraformational conglomerates. Fine to medium-grained sandstone is cross-bedded and embedded with intraformational conglomerate lenses or thin clay layers. The Kamliyal Formation sandstone is distinguishable from the underlying Murree Formation sandstone by its generally spheroidal weathering, availability of tourmaline, and lack of epidote, which is prevalent in Murree sandstone (Shah, 2009). Fig - 1(b) shows the stratigraphy column of Miocene in Rawalpindi group's Murree and Kamliyal Formations.

3. METHODOLOGY

The Murree and Kamli Formation of the Rawalpindi Group were sampled in Bagh Section in Kashmir Basin. The Section lies at 73°30'17.3" E and 34°0'5.73" N. Field and laboratory studies were done to investigate sandstone's petrographic and physio-mechanical properties for construction applications. Materials for laboratory investigation were obtained from the Rawalpindi group's Murree and Kamli Formations. The core drilling was performed at the engineering laboratory of the University of Azad Jammu and Kashmir.

3.1 Field Work

Fieldwork was conducted in the research area to collect representative samples for laboratory analysis. According to the availability of the selected standard, samples are commonly provided in boulder or crushing conditions. The present research focuses on four bulk samples from the Rawalpindi group's Murree and Kamli Formations. The mineralogical and Physio-mechanical properties of the rocks were determined based on laboratory analysis and field observations.

3.2 Laboratory Work

Various geotechnical tests were carried out on the specimens utilizing AAASHTO-advanced methodologies (Officials, 2011). Four cores were drilled from each sample with 54 mm diameter and 108 mm dimension. The cores were analyzed for several physio-mechanical properties including water absorption and specific gravity, point load strength Test, P-wave velocity (Vp), Brazilian test, Uniaxial Compression Strength test (UCS), and slake durability test. Uniaxial compression strength (UCS) significantly correlated with all investigated physio-mechanical parameters. In addition, the thin sections were prepared for each core sample to detail petrography.

3.3 Petrographic Analysis

The sedimentary rocks were the focus of the petrographic investigation. Relevant and representative sandstone samples from the study region were selected from well-exposed rock units. The thin slice was made in the laboratory and examined under a microscope. Petrographic investigations are commonly used to study the reactive components in rocks (Astm, 2003). The present petrographic investigation focused on minerals, grain size, grain shape, and degree of sorting. A rigorous petrographic examination was used to find unique depositional environments and diagenetic fabric to better understand the probable depositional settings and diagenetic material on the engineering features of the underresearched rocks. Modal analysis is a rock petrography identification method that counts the distinctive minerals found in each rock type and calculates their mineralogical composition and crystal formation percentage age. In addition, the thin sections were prepared for each core sample to detail petrography. In each thin Section, at least 300 points counts were considered for model mineralogy. The petrographic investigation focused on minerals, grain size, grain shape, and degree of sorting. The samples were chosen for their mineralogical composition, which significantly impacts aggregate material quality (Kandhal et al., 2000; Mpallatsas et al., 2010). According to calculate the percentage of Mineral Composition, use the equation below (Jethro et al., 2014).

$$Cm = \frac{Tm}{T_{tm}} \times 100 \quad (1)$$

T_m denotes the total number of counts for a mineral, whereas T_{tm} denotes the total number of counts for the whole mineral, and Cm is the percentage of mineral composition (%).

4. RESULTS AND DISCUSSION

4.1 Petrography

The sandstone from Murree and Kamli formations predominantly consists of quartz, feldspar, and lithics as framework grains. The percentage of framework grains varies throughout the Formation. Quartz is the most prominent mineral in the Kamli Formation of Chamman, Bagh (KCB), with an average abundance of 40%. Grains with uniform and undulating extinction are quite common. Both monocrystalline and polycrystalline varieties of quartz occur in the studied samples (Figure 2d). Monocrystalline quartz with uniform extinction is more common than monocrystalline quartz with undulatory extinction. Fractures are observed in quartz grains (Figure 2c). Feldspar contained microcline and plagioclase constituting about 8%. Rock fragments occur up to 30%. The clasts are sedimentary, igneous, and metamorphic rocks. Rock fragments exhibited various shapes from rounded to subrounded and elongated. The igneous fragments are 10% sedimentary clasts that form up to 14%, and Metamorphic clasts constitute 06% (Table 1).

Table 1: The Petrographic Analysis of The Study Area				
Model Mineralogical Composition	Samples			
	KCB	MSB	MCH	
Quartz	40	37	36	
Feldspar	08	06	05	
Rock Fragment	Igneous clasts	10	07	07
	Metamorphic	06	09	10
	Sedimentary	14	16	16
Accessory Minerals	Muscovite	03	03	03
	Biotite	02	04	02
Cement	Calcite	10	11	13
Matrix		07	07	08
Total	100	100	100	

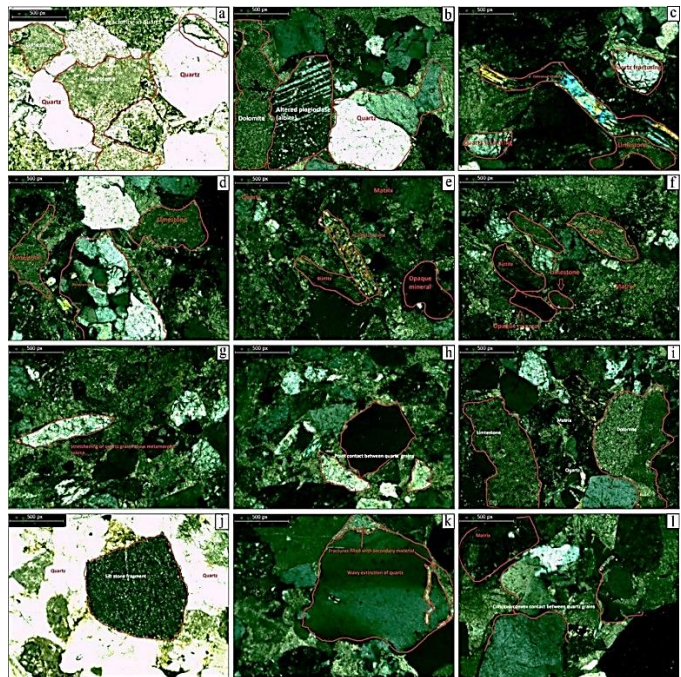


Figure 2: Photomicrographs of composition and texture of sandstones on a thin section of Murree Formation of Chamman, Bagh (KCB) shows (a) plain polarized light showing limestone and quartz (b) dolomite, quartz, and altered plagioclase. (c) deformed muscovite; Shuja Abad, Bagh (MSB) shows (e) biotite, muscovite, opaque minerals, quartz, and matrix (f) biotite, phyllite, opaque mineral, and limestone lenses (g) stretching of quartz grain (metamorphic sources) (h) point contact between quartz; Chakkar Muzaffarabad (MCM) (i) limestone, dolomite, quartz, and minerals (j) siltstone fragments and quartz (k) wavy extension of quartz and fractured filled with secondary materials (l) concave-convex contact between quartz grains.

Accessory minerals are not very abundant in the sample. Muscovite and Biotite are 3% and 2%, respectively. At some portions, the Muscovite is highly altered (Fig 2. c). In addition, 10% of calcareous cementing materials are recorded. Limestone and quartz could only be seen in plain polarized light (Figure 2a, and Figure 2d). Several grains of Tourmaline are observed. The dolomitic clasts were also recorded in a few samples. In some portions, the alteration of plagioclase and quartz is observed (Figure 2b). MSB (Murree Formation of Shuja Abad, Bagh) has a total of 37% quartz (Table 1), with angular to subangular and rounded shapes. In quartz, grains with uniform and undulatory extinction are common. In some portions, the stretching of quartz grains indicates their metamorphic source (Figure 2g). One of the prominent features is the point contact between the quartz grains (Figure 2h). Rock fragments included containing sedimentary 16%, metamorphic 9%, and igneous 7%, making a total of 32% fragments (Table 1). Feldspar in the sample is 6% (Table 1). Among accessory minerals, Muscovite and Biotite are 3% and 4%, respectively (Table 1; Figure 2e). The calcareous cementing materials are up to 11%, while about 7% can be observed as a matrix (Table 1). Opaque minerals such as phyllite are also present (Figure 2e, and Figure 2f). Limestone lenses are also observed (Figure 2f).

MCM (Murree Formation of Chakar, Muzaffarabad) has a total of 37% quartz (Table 1). The wavy extension in quartz can be seen with fractures filled with secondary materials (Figure 2k). The boundaries among quartz and feldspar grains in the thin sections investigated are tangential, long, concavo-convex, and sutured. (Figure 2l). Rock fragments comprise a total of 33% of the sample, of which sedimentary clasts are 16%, metamorphic fragments are 10%, and igneous clasts are 7%. Feldspar is the MCM

sample is 5% (Table 1). The accessory minerals such as Muscovite and Biotite have a share of 3% and 2%, respectively (Table 1). The calcareous cementing materials reach up to 13% while about 7% can be observed as a matrix. Limestone and dolomite are also observed (Figure 2i). In the matrix of this sample, there could be seen siltstone fragments embedded in some areas (Figure 2g).

4.2 Physio-Mechanical and Statistical Analysis

4.2.1 Water Absorption and The Specific Gravity (SG)

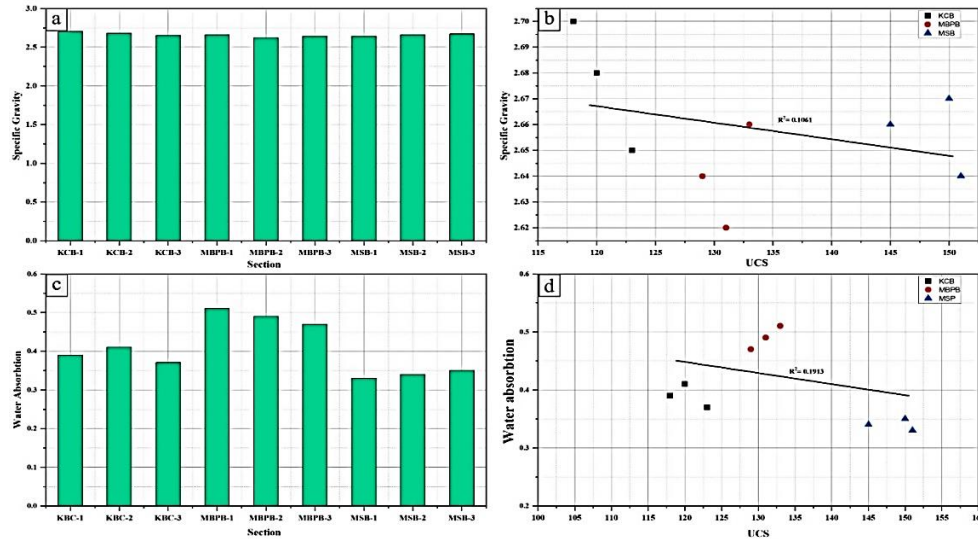


Figure 3: Shows the test result of (a) specific gravity (SG), (b) the Relationship between the unconfined compression test (UCS) vs specific gravity, (c) the test result of water absorption, (d) the Relationship between unconfined compression test vs water absorption.

Water absorption and the specific gravity (SG) parameters indicate that aggregate is competent for usage in the base, sub-base, and surface layers (Ahsan and Gondal, 2016). Water absorption is greater in rocks with a higher porosity value (Sajid et al., 2021). Aggregate with a greater specific gravity reveals its compaction nature, which is associated with its mineralogical structure (Khan, 2000). Specific gravity and water absorption test has been carried out for nine rock samples to determine the specific gravity and absorption. The result values of Specific Gravity (SG) samples of KCB-1, KCB-2, KCB-3 MBPB-1, MBPB-2, MBPB-3 and MSB-1, MSB-2, MSB-3 are varying from (2.70, 2.68 and 2.65), (2.66, 2.62 and 2.64) and (2.64, 2.66 and 2.67) respectively, with average values of 2.67, 2.64 and 2.65 respectively as shown in figure (3a). Water absorption values for KCB-1, KCB-2, KCB-3 MBPB-1, MBPB-2, MBPB-3 MSB-1, MSB-2, and MSB-3 are varying from (0.39%, 0.41%, and 0.37%), (0.51% 0.49% and 0.47%) and (0.33%, 0.34,% and 0.35%) respectively, with average values of 0.39%, 0.49%, and 0.34% respectively (Figure 3c).

In terms of laboratory studies, an aggregate type's Specific Gravity (SG) is widely considered to be a reliable predictor of its strength or quality (Hussain et al., 2022). Geotechnically, the SG of aggregates in pavement ranges from 2.6 to 2.7 up to 2.99 (84, 2013). The samples can be utilized on the pavement as a consequence of the findings. According to these results, all samples with a low water absorption value can be exploited as construction material in a rainy region, while those with a high value can be used in an arid area. The computed average specific gravity and water absorption values are within international standards (84, 2013). With correlation coefficients ($R^2 = 0.1061$) and ($R^2 = 0.1913$), the uniaxial compressive strength (UCS) of sandstone is correlated with its specific gravity (SG) and water absorption value. According to the results, it can be seen that specific gravity (SG) and water absorption are positively poorly correlated against unconfined compression strength (UCS) (Figure 3b, 3d) respectively. The specific gravity (SG) and water absorption values can be calculated by following formulae;

$$\text{Specific gravity} = \frac{\text{dry weight}}{\text{total volume}(V_s+V_w)-V_w} \quad (2)$$

$$\text{specific gravity (SG)} = \frac{W_d}{V_t - V_w}$$

V_w = Volume of water

V_s = Volume of a sample

V_t = Total volume

For water absorption;

$$\text{Water absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100 \quad (3)$$

4.2.2 Uniaxial Compression Strength (UCS)

In engineering practice, uniaxial compression strength (UCS) is one of the most commonly utilized criteria for the mechanical evaluation of rocks (Selçuk and Kayabali, 2015). Uniaxial compression strength (UCS) is one of the most significant methods for assessing rock shearing resistance (Farmer, 2012; West, 1994). The UCS values can be found by following equation;

$$\text{UCS} = P/A \text{ (KN/m}^2\text{)} \quad (4)$$

Where P = load at time of failure (lbs.)

A=Cross sectional area of the core (in^2)

The UCS values of KCB-1, KCB-2, KCB-3 MBPB-1, MBPB-2, MBPB-3 and MSB-1, MSB-2, MSB-3 are varying from (118(MPa), 120(MPa) and 123(MPa)), (133(MPa), 131(MPa) and 129(MPa)) (151(MPa), 145(MPa) and 150(MPa)) respectively, with average values of 120.3(MPa), 131(MPa) and 148.8(MPa) respectively (Figure 4a). The results indicate that the compression strength values are high to extremely high strength (Brown, n.d.; Deere and Miller, 1966; Fener et al., 2005; Piteau, 1970).

4.2.3 Point Load Strength Index (I_{s50})

The compressive or tensile strength of a rock has been evaluated indirectly using the point load index test (Akram and Bakar, 2007). The point load test is an easy method for determining rock strength designed to detect and classify rock material. For more than 20 years, the International Society of Rock Mechanics standardized and developed it and has been employed in geotechnical studies (ISRM 1985). Because it is highly correlated with compressive strengths, other strength parameters can be predicted using the point load strength index (ISRM 1985). Using the following equation, the applied force (P), the distance between the platens at failure (De or equivalent core diameter), and the point load index (I_s) were measured and computed:

$$I_s = \frac{P}{D_e^2} \quad (5)$$

The following equation was used to determine ($I_{s(50)}$) for a 50 mm core diameter.

$$I_{s(50)} = I_s \left(\frac{De}{50} \right)^2 \tag{6}$$

The point load values of KCB-1, KCB-2, KCB-3 MBPB-1, MBPB-2, MBPB-3 and MSB-1, MSB-2, MSB-3 are varying from (3.9(MPa), 3.4(MPa) and 3.7(MPa)), (5.6(MPa), 5.3(MPa) and 5.1(MPa)) and (5.5(MPa), 5.7(MPa) and 5.3(MPa)) respectively with average values of 3.6(MPa), 5.3(MPa) and

5.5(MPa) respectively (Figure 4b). According to the result, the shear strength values range from medium to high (Hatheway, 2009; ISRM 1985). Uniaxial compressive strength (UCS) of the sandstone was correlated with Point load strength index $I_{s(50)}$ with a good correlate coefficient ($R^2 = 0.6332$). The trend of the data demonstrates a rise in the Uniaxial compressive strength (UCS) with an increase in the point load index $I_{s(50)}$ (Figure 4c).

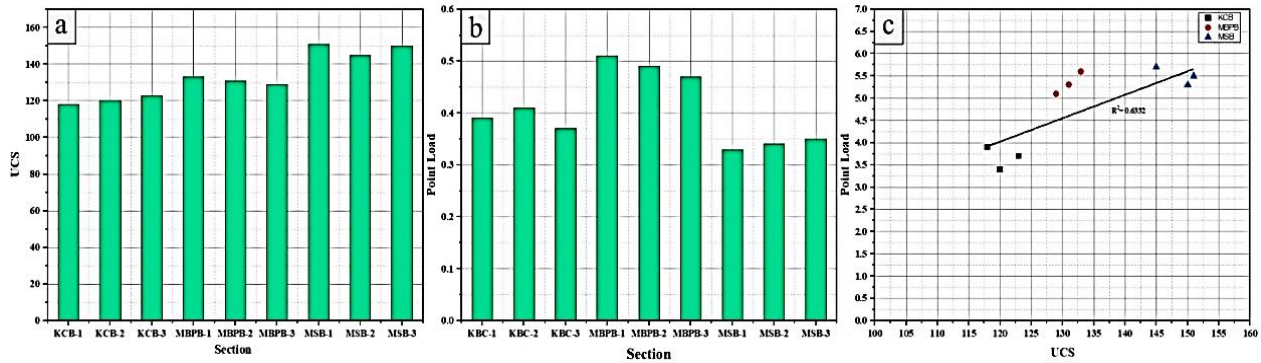


Figure 4: Shows the result of (a) the unconfined compression strength value (UCS), (b) shows the results of the point load index (IS50) and (c) the Relationship between the unconfined compression test vs point load index (IS50).

4.2.4 Slake Durability Test

The slake durability test is used to evaluate weathering resistance based on mineralogical composition and to quantify a rock sample’s resistance to weathering and decomposition. Disintegration occurs in various rock formations. The Slake Durability Test (SDT) was used to evaluate both intact samples and those that had been aged by drying wet and freeze-thaw cycles (Martinez-Bofill et al., 2004). As a result, samples break and disintegrate. During freeze-thaw cycles, the weakest samples degrade rapidly and show no linear term. The ageing cycles make it easier to distinguish between strong and weak rocks, making it possible to predict their behavior in the future with a great deal of accuracy (Martinez-Bofill et al., 2004).

The Slake durability index values of KCB-1, KCB-2, KCB-3 MBPB-1, MBPB-2, MBPB-3 and MSB-1, MSB-2, MSB-3 samples after first cycle are (99.5%,

98% and 99%) (99.3%, 98.6% and 98%) and (99.6%, 98.4% and 98%) respectively and the index values after second cycle of KCB-1, KCB-2, KCB-3 MBPB-1, MBPB-2, MBPB-3 and MSB-1, MSB-2, MSB-3 (98.5%, 97.2% and 98.8%) (98.7%, 98% and 97.2%) and (99.3%, 98% and 97.5%) respectively with average values after 1st cycle are 98.83%, 98.63% and 98.66% and the average values after 2nd cycle varying from 98.16%, 97.96% and 98.26% respectively. The average difference after first and second cycle are 0.67%, 0.67% and 0.40% respectively (Figure 5e). As a result, strength ranges from very high to extremely high (Franklin and Chandra, 1972). The 1st and 2nd cycles of the Slake Durability Index were plotted against the uniaxial compression strength (UCS) of sandstones, with correlated coefficient values of ($R^2 = 0.0011$) and ($R^2 = 0.0282$), respectively, and the findings revealed that there is no linear correlation (Figure 5f).

4.2.5 P-Wave Velocity

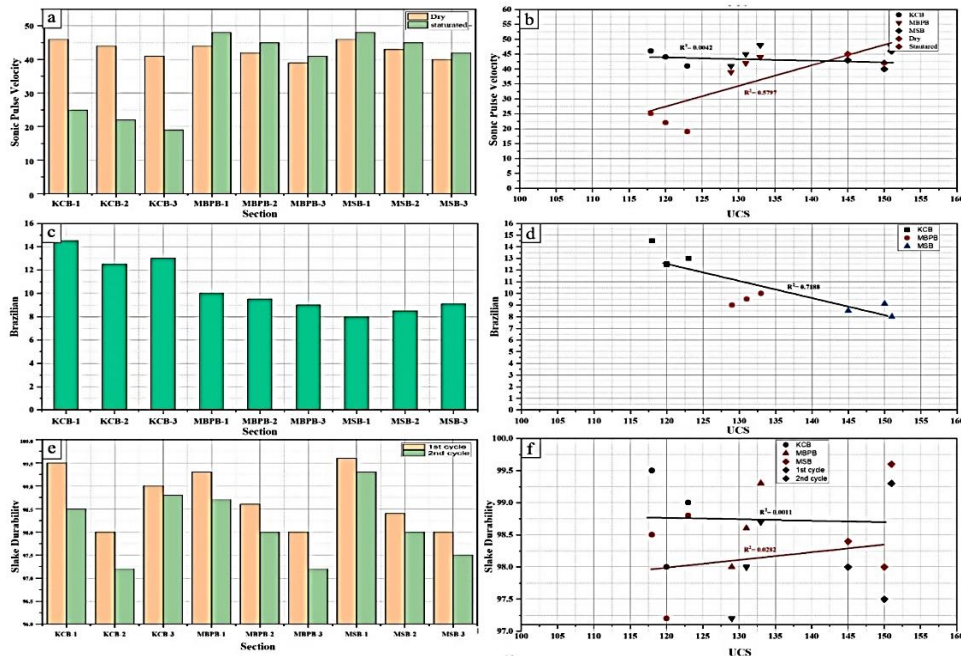


Figure 5: Shows the results of (a) sonic pulse velocity (b) the Relationship between the unconfined compression test vs sonic pulse velocity, (c) the Brazilian test, and (d) the Relationship between the unconfined compression test vs. the Brazilian test, (e) Slake durability test (f) Relationship between the unconfined compression test vs Slake durability test

P-wave velocity (V_p) techniques are well-established in stone sustainability. The reason for the prevalence of the method is that it’s quick and simple to apply in the field. It is used to identify fractures and faults in concrete, as well as to stabilize it. Pulse velocity is influenced by mineral composition, porosity, grain arrangement, water content, and the

existence of fissures. Macroscopic feature samples for determining velocity are comprised of the average total velocity in the minerals (Abdelaali et al., 2013). Pundit is used to measure the velocity of sound waves (longitudinal and shear waves) in core specimens (ASTM D2845-00).

$$v_p = \frac{s}{t} \tag{7}$$

P-wave velocity (Vp) measurements were conducted in both dry and saturated conditions. P-wave velocity (Vp) values of KCB-1, KCB-2, KCB-3 MBPB-1, MBPB-2, MBPB-3 and MSB-1, MSB-2, MSB-3 are varying from (46 Km/s, 44 km/s and 41 Km/s), (44 Km/s, 42 km/s and 39 Km/s) and (46 Km/s, 43 km/s and 40 Km/s) respectively in dry condition with average values of 43.66 Km/s, 41.66 km/s and 43 Km/s respectively and in saturated condition the values varying from (25 Km/s, 22 km/s and 19 Km/s), (48 Km/s, 45 km/s and 41 Km/s) and (48 Km/s, 45 km/s and 42 Km/s) respectively and average values are ranging from 22 Km/s, 44.66 km/s and 45 Km/s) respectively (Figure 5a). Porosity has a major impact on P-wave velocity (Vp). Pulse Velocity increases as porosity decreases (Abdulkareem et al., 2022). The result shows that the strength range both in dry and wet are in good condition. The relations of uniaxial compression strength (UCS) with P-wave velocity (Vp) are plotted both in dry and saturated conditions. The studied sandstones in saturated conditions investigated a moderate positive, simple linear relation with correlation coefficient values (R² = 0.5797), and no linear correlation is shown in dry conditions with correlation coefficient values (R² = 0.0042) (Figure 5b).

4.2.6 Brazilian Test

It is a technique for indirectly predicting the stretched behavior of brittle materials such as concrete and rock (Khanlari et al., 2015). Brazilian disc test (BD) results determine the tensile strength for splitting (Li and Wong, 2013). Samples are angled between 0 and 90 degrees during this test. The direction of loading can be used to measure orientation.

$$BTS = \frac{2P}{\pi Dt} \tag{8}$$

where P is the peak load that was detected during test and the specimen diameter is D and its thickness t.

To determine the failures behaviour for a specific inclination direction, the test is carried out on more samples. The result values of KCB-1, KCB-2, KCB-3 MBPB-1, MBPB-2, MBPB-3 and MSB-1, MSB-2, MSB-3 samples are varying from (14.5(MPa), 12.5(MPa) and 13.0 (MPa)), (10.0(MPa), 9.5(MPa) and 9.0 (MPa)) and (8.0(MPa), 8.5(MPa) and 9.1(MPa)) respectively and average values are varying from 13.33(MPa), 9.5(MPa) and 8.53(MPa) respectively (Figure 5c). As a result, all samples of Brazilian tensile can be used as construction material (Materials, 2016). The sandstone's uniaxial compressive strength (UCS) was correlated against the Brazilian test. The correlations of studied rocks show a good linear relationship between unconfined compression strength and the Brazilian test with a high correlate coefficient (R² = 0.7188) (Figure 5d).

5. COMPARISON BETWEEN BAGH SECTION AND JENA KOR SECTION

Table 2: Comparison Between Rawalpindi Group's Murree and Kamliyal Formations with Murree Sandstone from Jena Kor (FR Peshawar)		
Property/component	Jena kor (study area)	Rawalpindi group's Murree and Kamliyal Formations
Grain size	Very fine to medium	Fine to medium
Degree of sorting	Moderate to well (95%)	Uniform with wavy undulation
Angularity	Angular to sub-angular to sub-rounded	Angular to sub-angular to sub-rounded
Quartz	9.5-43.4 %	36 to 40%
Feldspar	---	5 to 8%
Other clasts	10.9-55.0 %	6 to 16%
Deformed micas	present	present
Total clasts	23.1-93.5 %	47 to 64%
Matrix / cement	6.9-77.0 %	7 to 8%
Matrix / cement composition	Calcite and iron oxide	Calcite, silt stone
UCS (MPa)	54.5-98.0 (77.07±21.61)	120.3 to 148.8 (MPa)
Specific gravity	3.12	2.64 to 2.67
Water absorption %	0.389%	0.34% to 0.49%

The uniaxial compression strength (UCS) values of the specimens under consideration differ significantly. A comparison of Murree and Kamliyal sandstones from the Rawalpindi group with Murree sandstone from the Jena kor Formation reveals a significant variation in terms of strength and petrographic aspects. The fluctuation in the comparative percentage of clasts that contain both quartz and matrix/ cement is noteworthy. The degree of sorting and Angularity is almost the same in both regions, and the Feldspar content is not present in the Jena kor area. Secondly, the strength value of specific gravity and water absorption is almost equal, whereas the unconfined value shows greater variation. According to the uniaxial compression strength result, the Murree and Kamliyal formation show high strength compared to the Jena kor study area. Sandstone from the Murree and Kamliyal formations is well within the range regarded suitable for use as dimensional stone and building materials and is thus ideal for use in heavy construction activities due to all of its physio-mechanical qualities. The comparison between Rawalpindi group's Murree and Kamliyal Formations with Murree is shown in (Table 2).

6. CONCLUSION

Based on the petrographical and physio-mechanical data on the measured parameters of nine specimens from the studied research region, the following conclusions may be drawn:

According to microscopic properties and matrix composition, Quartz dominates the Rawalpindi Groups sandstone. Quartz grains in Rawalpindi Group sandstones are angular to subangular, indicating a near source, whereas rounded to subrounded quartz grains indicate a distant source and that the grains got rounded through long migration. Non-undulatory monocrystalline quartz grains are formed by acidic plutonic igneous rocks such as granite, whereas undulatory monocrystalline and elongated quartz grains, as well as polycrystalline quartz grains, are formed by metamorphic rocks such as slate, phyllite, schist, gneiss, and quartzite. Plagioclase and Microcline in feldspar indicate that their source was granites and granite gneisses, whereas plagioclase was fractured during metamorphism or due to local tectonic action.

The accessory minerals of the study area including biotite, muscovite, and calcite, are secondary minerals generated by pyroxene and feldspar alteration. The accumulation of rock pieces strongly implies metamorphic, igneous, and sedimentary causes for the Rawalpindi Group sandstones. It is also observed that petrographic parameters such as contact type, grain shape and size, rock fragmentation with packing density, and contact have a considerable impact on the engineering qualities of sandstones. One of the inherent properties determining rock strength is mineralogical composition. Rocks with clayey binding materials are the weakest, while those with quartz as the binding material are the strongest, followed by calcite and ferrous minerals.

Physio-mechanical characteristics of Murree and Kamliyal formation Rawalpindi which include specific gravity and water absorption, uniaxial compressive strength (UCS), slake durability test, P-wave velocity (Vp) and Brazilian assessment revealed that its compression strength varies from medium to extremely high. The linear correlation analysis results showed that uniaxial compression strength (UCS) affected specific gravity, water absorption, slake durability index, P-wave velocity (dry). The other characteristics such as point load index, Brazilian tensile strength and ultrasonic pulse P-wave velocity (saturated) are controlled by uniaxial compression strength (UCS).

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that might have influenced the work presented in this article.

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