INTEGRATED GEOTECHNICAL AND MINERALOGICAL CHARACTERIZATION OF INDIGENOUS ROCKS FOR SUSTAINABLE CONSTRUCTION MATERIALS IN THE NORTH WESTREN HIMALAYAS — DISTRICT NEELUM , AZAD JAMMU & KASHMIR, PAKISTAN

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ABSTRACT: In the construction industry, the quality of raw materials like aggregates is of paramount importance. The use of non-durable or weak materials in a project's foundation can lead to structural failures, posing significant risks to both property and human safety. Geotechnical laboratory testing is essential to determine the strength and durability of these materials. Standard tests include Uniaxial Compressive Strength (UCS), Los Angeles Abrasion Value (LAAV), Aggregate Impact Value (AIV), Ultrasonic Pulse Velocity (UPV), specific gravity, water absorption, unit weight, and Schmidt hammer rebound tests. While these tests are crucial for assessing mechanical properties, it is equally important to consider the rock's mineralogical composition. A rock may exhibit high strength, but the presence of certain reactive minerals can initiate deleterious reactions over time. This study evaluated rocks from the Tithwal to Kel area in the Neelum District of Azad Kashmir for their suitability as construction material. The Uniaxial Compressive Strength values range from 52.66 MPa to 121.20 MPa. The Aggregate Impact Value ranges from 7.33% to 22.44%. The Los Angeles Abrasion Value ranges from 22.3% to 37.2%. Schmidt Hammer rebound values range from 40.33 to 50.33 Nm. Unit Weight values range from 1.73 to 2.48. Ultrasonic Pulse Velocity values range from 22.56 to 47.07 Hz. Specific Gravity values range from 2.45 to 5.82.The results indicated that, from a geotechnical perspective, all sampled rocks met the necessary strength criteria. However, it is recommended that some of these rocks be used with caution due to the presence of quartz minerals, which can participate in Alkali-Silica Reaction (ASR) when in contact with cement, potentially causing long-term durability issues.

Keywords: Construction material, Geotechnical Assessment, Raw material, Durability and strength.

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INTRODUCTION

The opening of different construction projects especially the mega construction projects are the important part of the government policy of all countries to decrease the rate of unemployment and to increase the development rate of the country. The material strength and classification especially rock material strength and classification is used to design the construction of different engineering projects and to maintain the quality of construction during working phase. The chief component of concrete are aggregates (i.e. up to 75% by concrete volume) that significantly influence the concrete properties and mixture proportions (Kosmatka et al., 2003[1]). The aggregates are the main component of concrete and also the most universal construction material used in construction of buildings, dams and transport infrastructure such as roads, railways and airport runways. The mechanical properties of concrete greatly affected by the properties of aggregates Furthermore, in high strength concrete the importance of aggregate strength cannot be ignored (Ayub et al., 2012[2]). The aggregate properties have great influence on engineering properties of concrete such as durability and hardness. Properties of aggregates are very important in the selection of good quality and performance bound aggregate for use in construction (Ahsan et al., 2000[3]). The basic engineering properties of rock aggregates are mostly measured from laboratory testing. Quality of crushed aggregate is determined on the basis of physical and mechanical properties of rock such as durability, abrasion and petrography (Khan et al., 2013[4]). The most important properties of construction materials are compressive strength, abrasion resistance and impact resistance and these properties should not be ignored at any phase of construction. Aggregates which do not have adequate hardness and abrasion resistance, may cause construction and performance problems (Wu et al., 1998[5]). The engineering performance of construction materials is strongly connected to their physical properties (Krynine and Judd, 1957[6]).UCS oldest simplest test is used to determine the uniaxial compressive strength, and one of the most convenient and useful ways for determining the strength of the strength of rocks (Jaeger and Cook, 1979[7]). The LAA test and AIV test measures the resistance of aggregate to wear due to attrition between rock particles and also to impact and crushing by steel spheres (Fernlund, 2005[8]; Kahraman and Fener, 2007[9]) The igneous and some metamorphic rocks are preferable to use as aggregate. Giaccio et al (1992[10]) studied the effect of coarse aggregate types such as basalt, granite and limestone on the mechanical properties of high-strength concrete and they reported that coarse aggregates such as basalt and granite have higher strength than lime stone. Tugrul, A., & Zarif, I. H. (1999[11]) established a direct relationship between minerlogical and mechanical properties of granatic rocks used for construction material.District Neelum, Azad Kashmir area generally consist of igneous and metamorphic rocks. The present study is focused on aggregate characterizations of rock units from Tithwal to Kel area North Western Himalayas, district Neelum, AJK, Pakistan. The study area lies from Tithwal to Kel North Western Himalayas Neelum Valley Azad Kashmir and lies between longitude 73^0 55' 55.8''and 74° 20′ 54.8″ and latitude 34^0 37' 42.4''and 34° 47′ 42.4″. The Study area is about 60 km from Muzaffarabad city. The study area covers an elongation strip along Neelum road. The area is easily accessible by Neelum Valley road which connects District Neelum and District Muzaffarabad. The main aim of this research is to propose a cost-reduction strategy using both mechanical and minerlogical studies for the ongoing mega-projects in Azad Kashmir. The core problem identified is the reliance on construction materials sourced from other provinces, which substantially inflates project budgets through high transportation costs. The study will investigate the feasibility of local material extraction within the respective districts as a means to achieve significant cost savings.

Geology of Study Area: The rocks in Neelum valley are mainly composed of metamorphic and igneous origin. The rocks of study area are Sharda Formation, Tanol Formation and Mansehra type Granite (Table 1).

Table 1: Geological succession of the study area. (Malik et al, 1996[12]).

Formation	Member	Age
Manshera Type Granatic Intrusions	Jura Granite,Keran Granite Gneiss, Danjar Grantoid,	Late Cambrian
Tanol Formation	Bata Quartzite, Athmuqam Quartzite, Banchattar Quartzite	Precambrian to Cambrian
Sharda Formation	Changan marble, Lawat Amphibolite, Kel Granite Gneiss	Precambrian

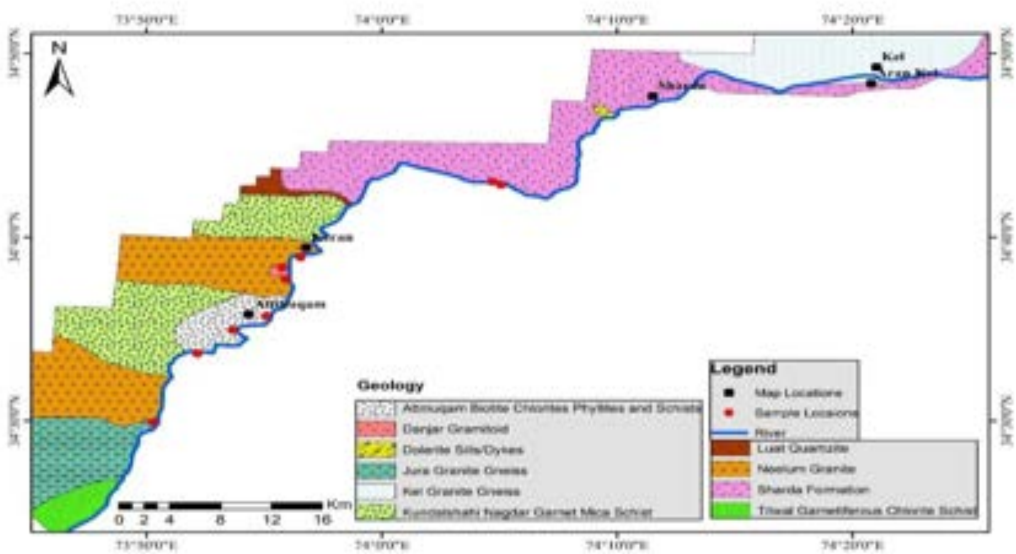

Figure 1: Geological strip mapping along Neelum valley road from Tithwal to Tao butt. (Compiled after Nespak, 2003[13]).

Field Sampling: The study area was critically inspected during field survey to mark the areas having better rock exposure for collecting the samples with some preventive measures and adequate rock samples were collected. The samples were named and numbered according to the localities and rock formations such as Jura Granite (JG), Danjar Granitoid (DG), Bata Quartzite (BQ), Athmuqam Quartzite (AQ), Changan Marble (CHM) and Lowat Amphibolite (LA) (Table 2).

Figure 2: Field Sampling of different formation for lab testing.

(a) Changan Marble **(b)** Lowat Amphibolite **(c)** Bata Quartzite **(d)** Athmuqam Quartzite **(e)** Banchattar Quartzite **(f)** Kel Granite Gneiss **(g)** Jura Granite **(h)** Danjar Granitoid

Table 2: Samples name, sample IDs, sample localities and coordinates.

Sample name	ID	Location	Northing	Easting	Elevation
Jura Granite /Gneiss	(JG)	Jura	34°29′55.49″	73°50′ 17.2″	1275 m
Danjar Granitoid	(DG)	Danjar	34° 27′ 38.4″	73° 55′ 45.8″	1532 m
Keran Granite	(KG	Keran	34° 38′ 54.4″	73° 56′ 32.7″	1506 m
Kel Granite Gneiss	(KGG)	Kel	34° 47′ 42.4″	74° 20′ 54.8″	2038 m
Bata Quartzite	(BQ)	Bata	34° 33′ 39.7″	73° 52′ 9.8″	1364 m
Athmuqam Quartzite	(AQ)	Athmuqam	34° 34′ 56.5″	73° 53′ 40″	1362 m
Banchattar Quartzite	(BQ)	Banchattar	34° 35′ 42.4″	73° 55′ 5.5″	1411 m
Changan Marble	(CHM)	Changan	34° 42′ 51.3″	74° 5′ 3.7″	1877 m
Lowat Amphibolite	(LA)	Lawat	34° 43′ 2.1″	74° 4′ 41.12″	1859m

Geotechnical Analysis: The engineering properties such as Impact resistance, Abrasion resistance, Strength were determined in accordance with American Society of Testing Materials (ASTM), British Standard (BS) Ulusay, R. (Ed.). (2015) [14]. The results of selected samples are shown in Table 3.

Table 3:Table showing the test results of selected rock samples RUW (Robbed Unit Weight) URUW (Unrobbed Unit Weight) SPG (Specific Gravity) WA (Water Absorption) USPV (Ultra Sonic Pulse Velocity) UCS (Unaxial Compressive Strength) AIV (Aggregate Impact Value) LAAV (Loss Angeles Abrasion Value) SSV (Schmidt Hammer Rebound Value).

S.No	Samples ID	RUW g/cm3	URUW g/cm3	SPG g/cm3	WA (%)	USPV (hertz)	UCS (MPa)	AIV (%)	LAAV (%)	SSV (Nm)
1	JG	1.74	1.73	3.94	0.41	32	67.05	13.9	34.83	41.67
2	DG	1.81	1.79	2.45	0.36	47.06	89.64	12.8	35.26	44.66
3	KG	1.84	1.83	4.31	0.34	30.06	121.2	13.97	30.36	46.35
4	KGG	1.73	1.72	3.7	0.42	25.9	100	14.46	37.2	46
5	AQ	2.3	2.28	5.77	0.16	22.56	70.07	7.83	22.3	49.33
6	BUQ	2.3	2.28	5.49	0.19	25.63	76.68	8.2	28.04	46.34
7	BQ	2.3	2.28	5.82	0.21	23.83	87.73	7.33	30.4	50.35
8	CHM	2.22	2.47	3.23	0.25	30.23	52.66	22.47	38.4	43.66
9	LA	2.48	2.21	2.53	0.57	37.36	69.6	18.36	24.34	40.35

Figure 3: Figure showing prepared cubes and cylinder samples for lab testing

The conducted test on the rock sample at Engineering geology lab of University of Muzafrabad AJK, Kashmir Pakistan are:

Unit weight test (ASTM C-128): To find out the unit weight and voids in the samples of coarse aggregates unit weight test is carried Nine samples collected from different location were selected and subjected to unit weight test. These samples were tested according to ASTM C-128. The Rock samples exhibit small variation in unit weight (Figure 4, 5; Table 3).

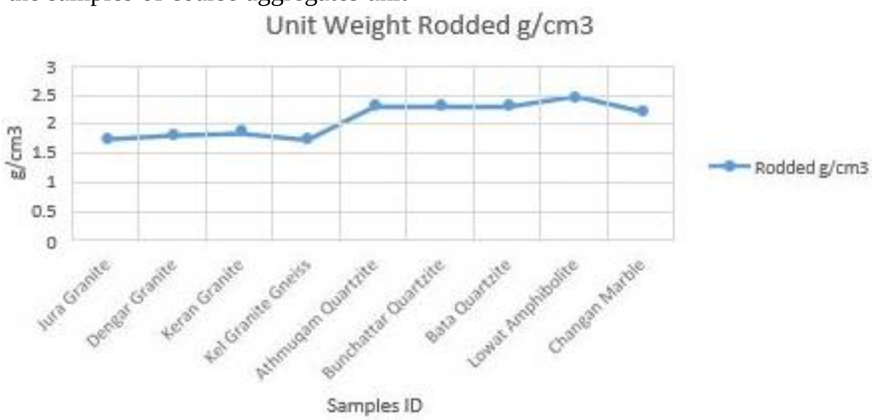

Figure 4: Rodded Unit weight values of selected rock types of the research area.

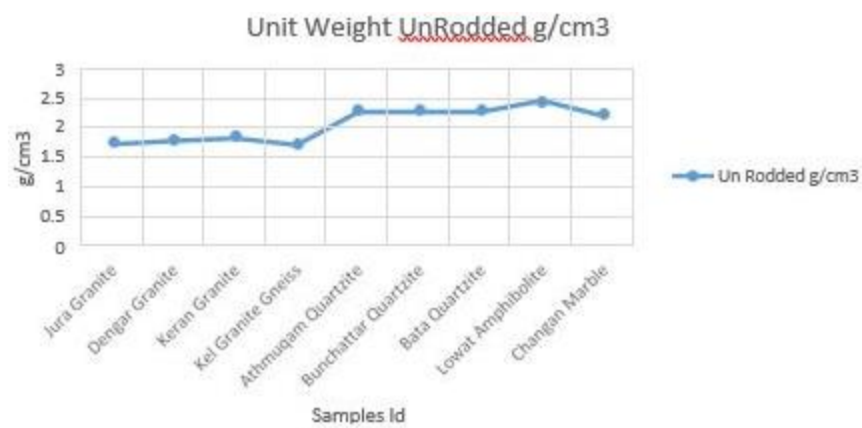

Figure 5: Un-rodded Unit weight values of selected rock types of the research area.

Specific gravity and water absorption (ASTM C-127): Specific gravity and water absorption test of rock aggregate is deal to assess the strength or quality of material. The test was carried out on Nine samples collected from different locations of study area. (Figure 6; Table 1).

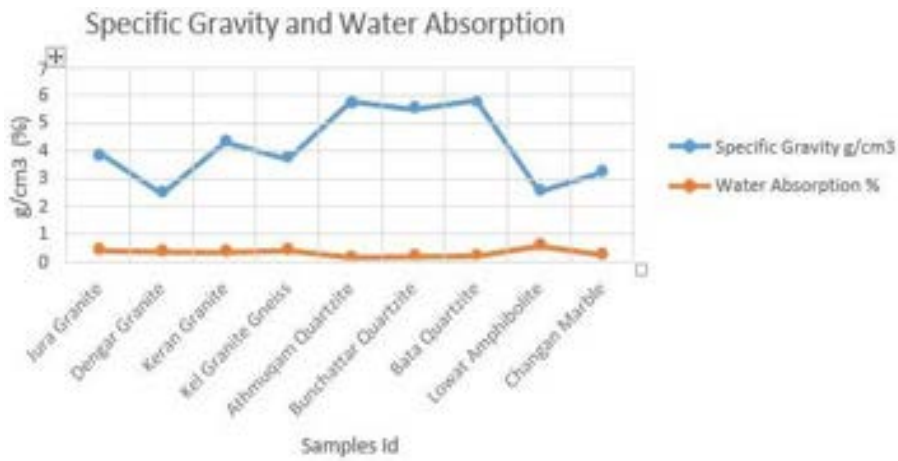

Figure 6: Specific gravity and Water absorption test values of selected rock types of the research area.

Ultrasonic pulse velocity test (ASTM C597-16): The Ultra Sonic pulse velocity test is a type of non-destructive testing and was carried for the assessment of the strength and quality of rock samples. The test was performed on Nine samples having different locations according to ASTM-597. The Rock samples exhibit variation in the ultra-sonic velocity (Figure 3.4; Table 1).

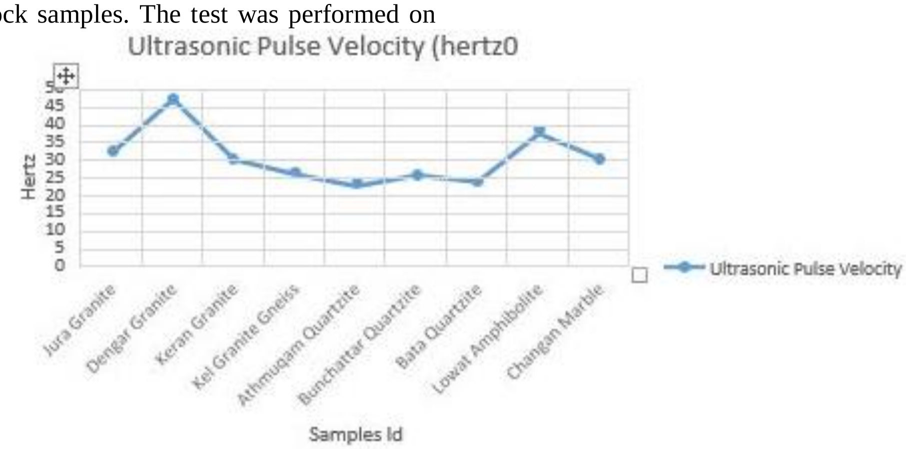

Figure 7: UPV values of selected rock types of the research area.

Uniaxial compressive strength test (ASTM D-4543): The uniaxial compressive strength test was carried to find out the strength of rock Samples. The UCS test was performed according to ASTM 4543. Nine samples belong to different localities were selected and tested for strength values. The international standard strength classification table of the UCS is used to classify rock samples. The UCS test show variation in the strength of rock samples Compressive strength is reliant on upon the specific gravity, petrographic properties and the differences in compressive strength appear due to variations in these properties (Table 1; Figure 3.5).

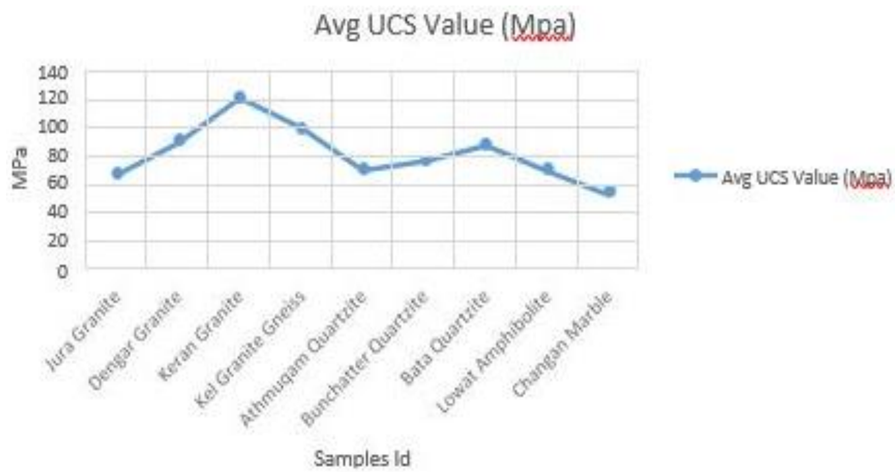

Figure 8: UCS values of selected rock types of the research area.

Aggregate impact value test (BS 812, 2000): To find out the resistance power of the rock samples against sudden shock or impact the Aggregate Impact Value test was carried out. Nine samples from different locations were selected and tested according to BS 812. The rock samples of the study area show variation in the AIV. These variations are due to differences in specific gravity, water absorption, lithological differences and petrographic composition. These fluctuations indicate that aggregates have good impact resistance if the specific gravity is high and porosity is low. These variations show that samples with low values exhibits strong resistance against sudden impact, whereas samples with high values shows poor resistance against sudden impact (Figure 9; Table 1).

Loss angeles abrasion value test (LAAV; ASTM C-535): To measure the toughness and abrasion resistance of the rock samples against crushing degradation and disintegration the Loss Angeles abrasion test was carried out according to ASTM C–535. Nine samples belong to different places were subjected to Loss Angeles abrasion value test. The Loss Angeles abrasion test show variation in abrasion resistance of rock samples. The lost percentage is generally associated with specific gravity, lithological composition and water absorption. These variations indicate that aggregates are durable enough against abrasion if the specific gravity is high and water absorption is low. These variations show that aggregates with low value express strong resistance against wearing action, whereas aggregates with high values show poor resistance against wearing action. (Figure 10; Table 1).

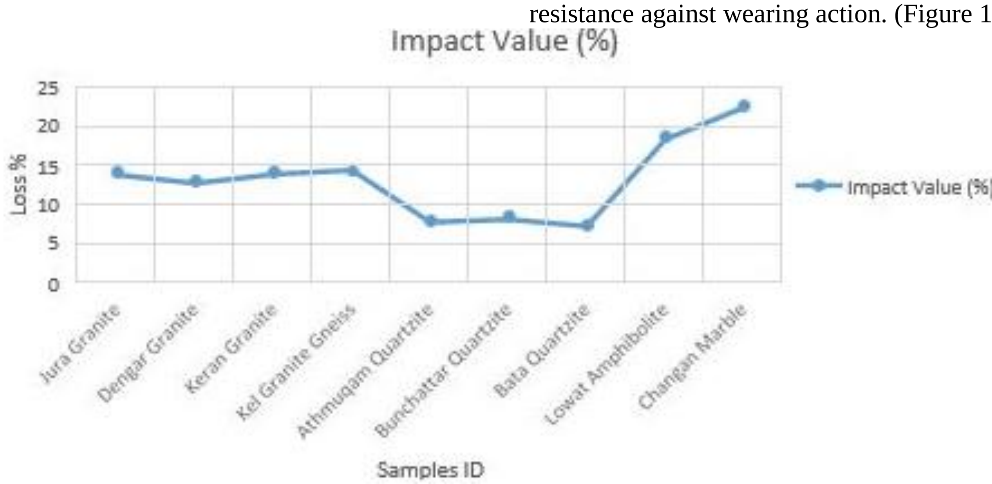

Figure 9: AIV of selected rock types of the research area.

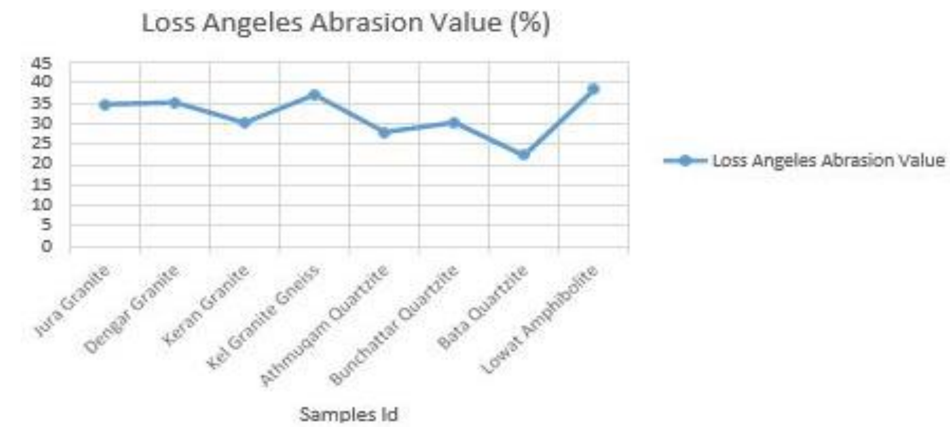

Figure 10: LAAV of selected rock types of the research area.

Schmidt hammer rebound value test (ASTM D-5873):The strength of a rock samples without destruction was measure through Schmidt hammer test. The Schmidt hammer test was performed according to ASTM D-5873 on Nine samples collected from different Localities. The international standard classification table for Schmidt hammer test is use to classify the rock material. The rock samples exhibit small variation in Schmidt hammer strength. The Schmidt strength relay upon physical properties and composition of rocks. Probably, these variations are due to differences in specific gravity, abrupt change in lithology and petrographic properties (Figure 11; Table 1).

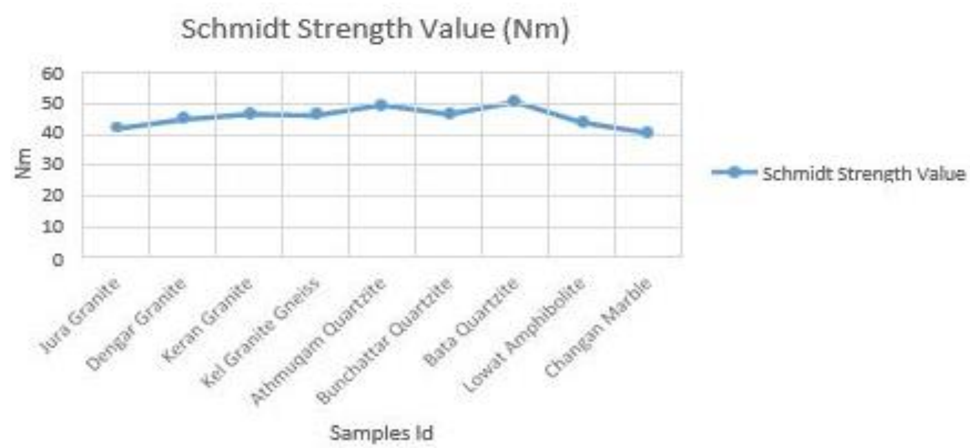

Figure 11: Schmidt hammer rebound values of selected rock types of the research area

Correlation of Mechanical and Physical Properties: The mechanical properties are generally associated with physical properties such as specific gravity and water absorption. The graph show that with increase in specific gravity values, the values of mechanical properties are also increases (Figure 12). Aggregates with low values of specific gravity are generally weaker than those with high specific gravity. Aggregates with low values of water absorption are stronger than those with high value of water absorption. The graph shows that best rock for building material is Keran Granite.

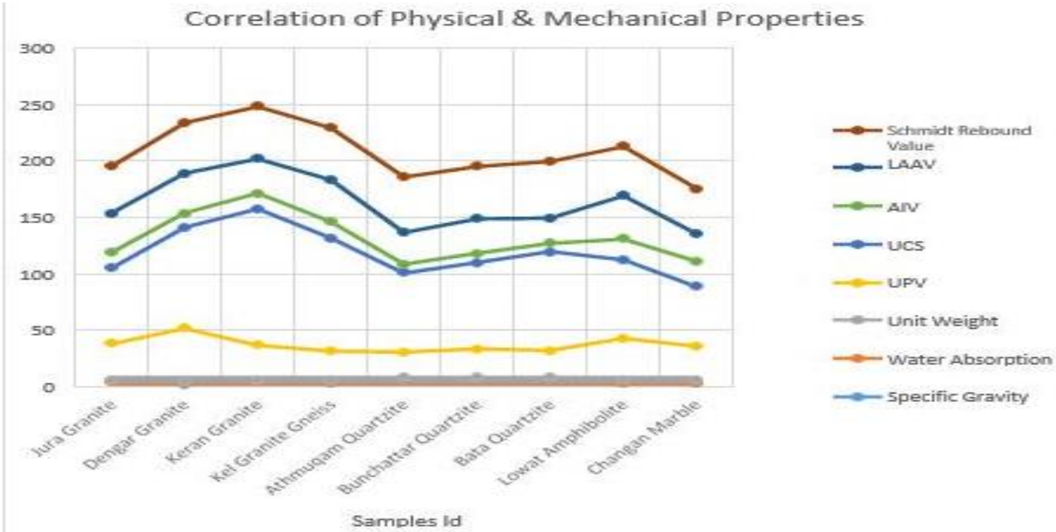

Figure 12: Correlation of Physical and mechanical properties

Petrography of Exposed Rock Samples From Tithwal to Kel: Petrography is the study of rocks with the help of petrographic microscope to address the detailed mineralogy and textural characteristic of the rocks. On the basis of physical, mineralogical and textural variation on outcrop scale samples were collected from the field area. For microscopic examination the collected rock samples were crushed, grinded and fabricated to prepare thin sections of rock samples Petrography includes the identification of the rock forming minerals, textural relation between the grains and then the volume percentage of different minerals in the rock (Haider & Akhtar 2025[15]).

Jura Granite Gneiss: The Jura granite comprised of quartz content 31% to 36%, feldspar 33% to 39%, and plagioclase 18% to 20%. The minor minerals biotite content 5% to 9%, muscovite content 1% to 3%, and opaque minerals 1% (Figure 13).

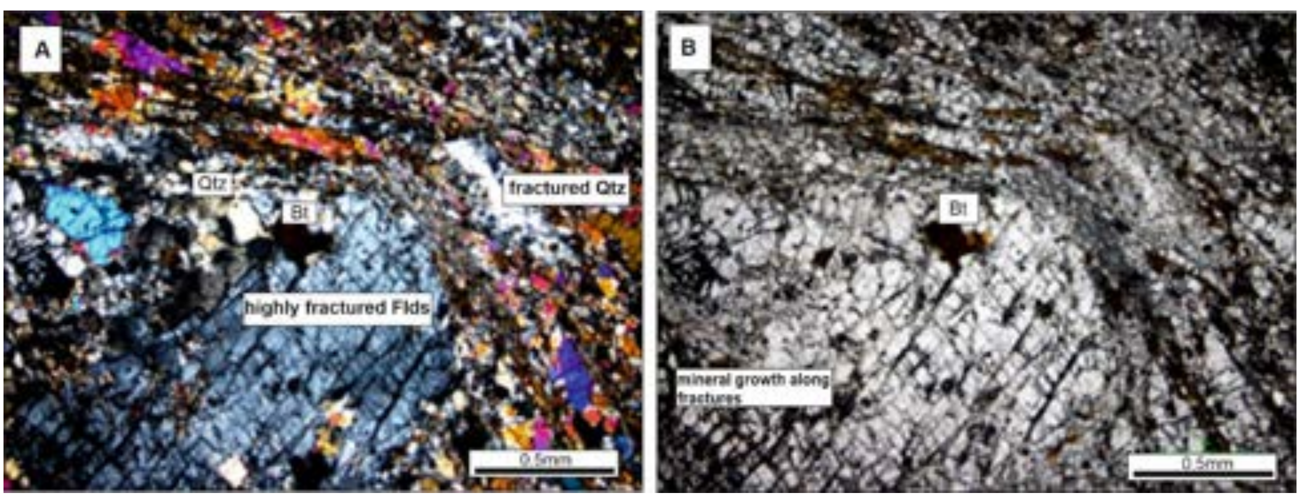

Fig. 13: (A) Cross Nicol and (B) PPL photographs showing fractured quartz (Qtz), fractured plagioclase feldspar (Flds) in shadow zone and foliated biotite mica (Bt) in the pressure zone showing orientation of stresses in Jura Granite.

Danjar Granitoid: The Danjar granitoid possess quartz 30% to 37%, feldspar 25% to 30%, and plagioclase 18% to 21%. Minor minerals biotite 8% to 10%, muscovite 5% to 9%, and opaque minerals 1% to 2% (Figure 14).

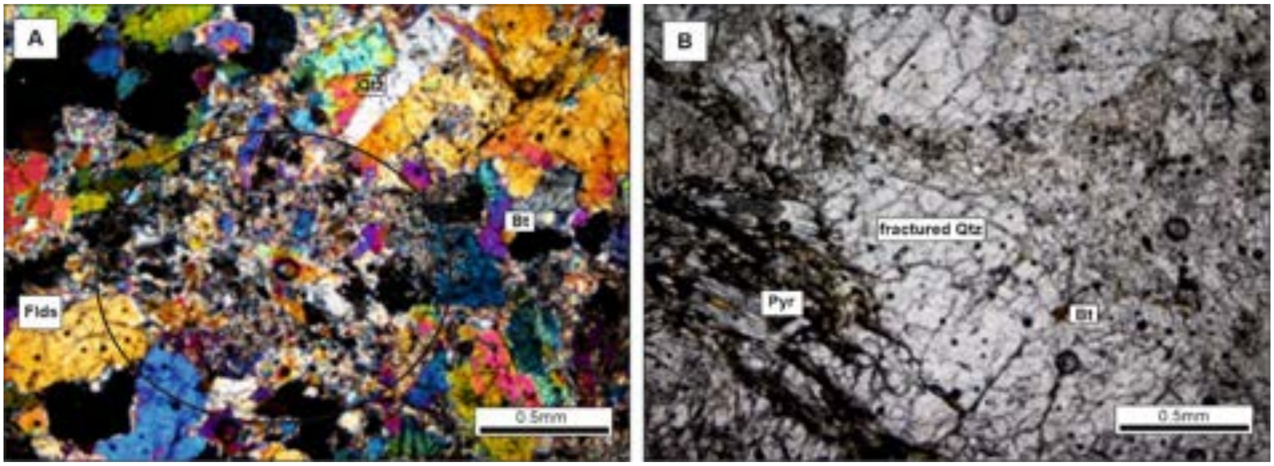

Fig. 14: (A) Cross Nicol, showing mineral assemblage as circled in center, (B) plane polarized light (PPL) showing fracture d Quartz (Qtz), Pyroxene (Pyr) and Biotite (Bt) in Danjar Granitoid.

Keran Granite Gneiss: The Keran granite includes quartz 33% to 35%, feldspar 27% to 29%, and plagioclase 23% to 25%. Minor minerals biotite 7% to 8%, muscovite 3% to 2% (Figure 15).

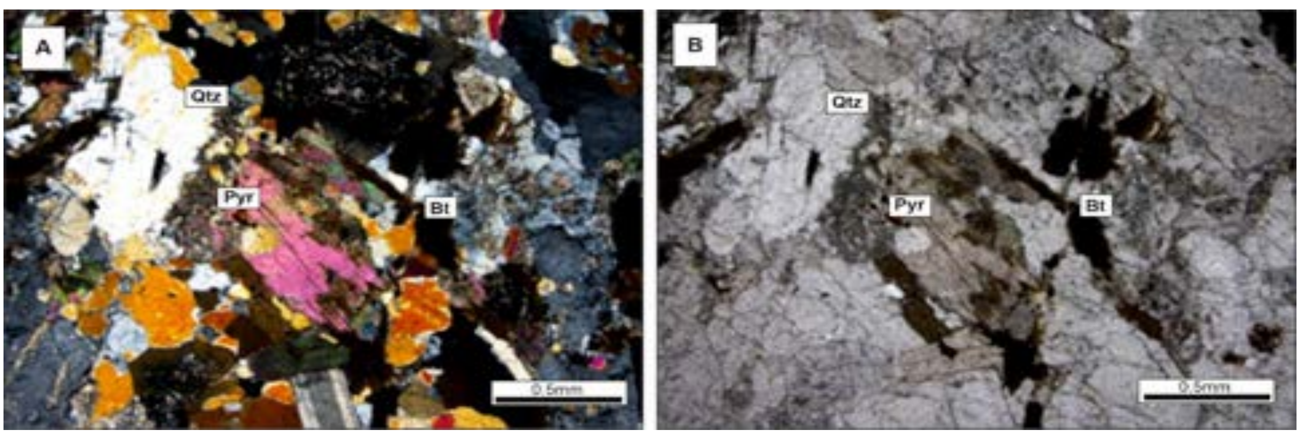

Fig. 15: (A) Cross Nicol, (B) plane polarized light (PPL) showing mineral assemblage and texture having mineral growth along fractures respectively in Keran Granite. Observed minerals are Quartz (Qtz), Pyroxene (Pyr) and Biotite (Bt).

Kel Granite Gneiss: The Kel granite gneiss includes quartz 37% to 40%, feldspar 20% to 23%, and plagioclase 30% to 33%. Minor minerals biotite 5% to 8%, opaque mineral 1% to 2% (Figure 16).

Athmuqam Quartzite: The Athmuqam Quartzite is dominantly composed of quartz 97% to 98% and with minor of feldspar striation traces 1% to 3%. (Figure 17).

Banchattar Quartzite: The Athmuqam quartzite is dominantly composed of quartz 98% to 99% and opaque mineral may be hematite 1% to 3%. The quartz grains are subrounded to sub angular. The muscovite show peacock color (Figure 18).

Bata Quartzite: The Athmuqam quartzite is dominantly composed of quartz 98% to 99% and opaque mineral may be hematite 1% to 3%. The quartz grains are subrounded to sub angular. The muscovite show peacock color (Figure 19).

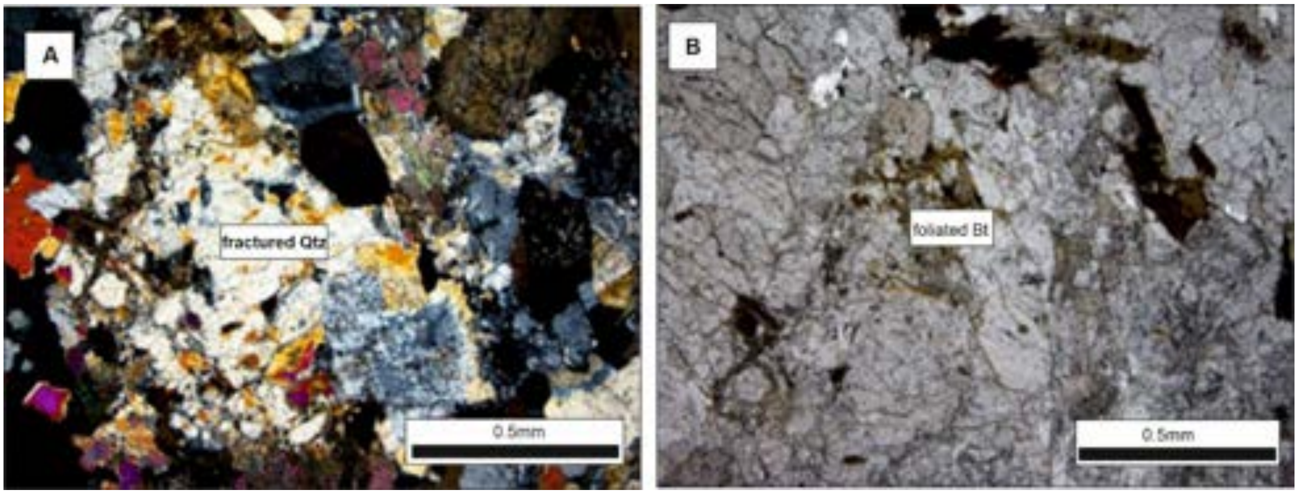

Fig 16: (A) Cross Nicol, photograph showing fractured quartz in the shadow zone and in (B) foliated biotite mica in the pressure zone showing orientation of stresses in Kel Granite Gneiss.

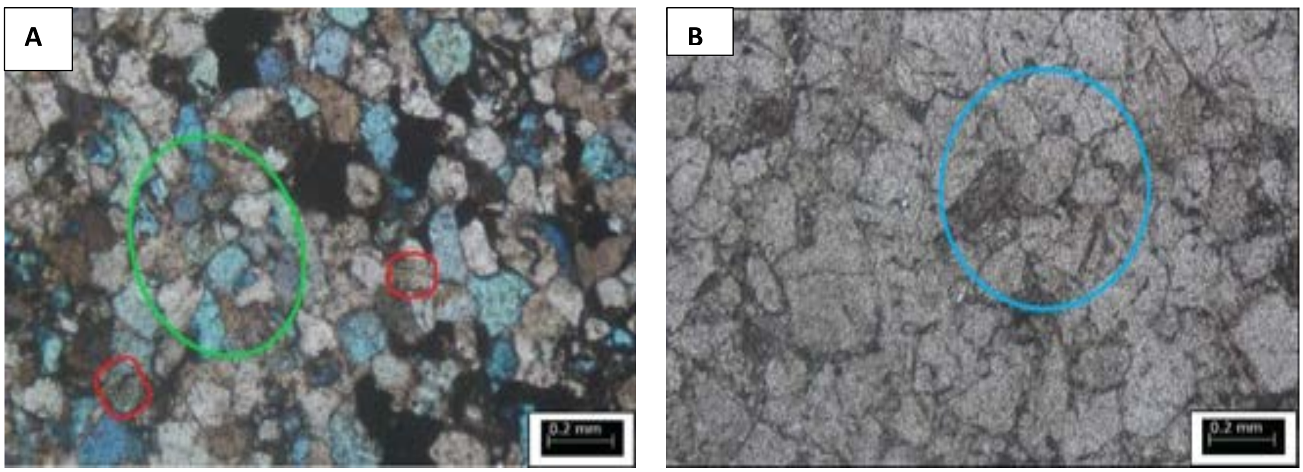

Figure 13: (A) Cross Nicol Photomicrograph of Athmuqam quartzite, green circle is showing quartz and red circles are showing traces of feldspar striations. (B) PPL Photograph of Athmuqam quartzite, blue circle is showing quartz.

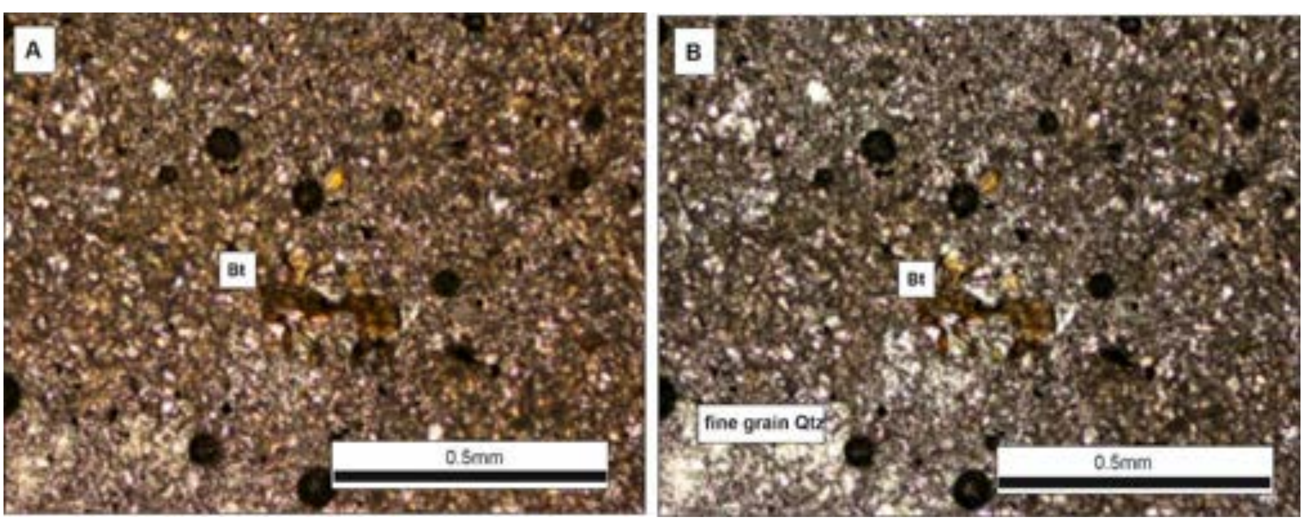

Fig. 18: Showing photomicrograph of Banchattar Quartzite, (A) Cross Nicol and (B) PPL respectively, Showing phenocryst of biotite in the very fine grained quartz.

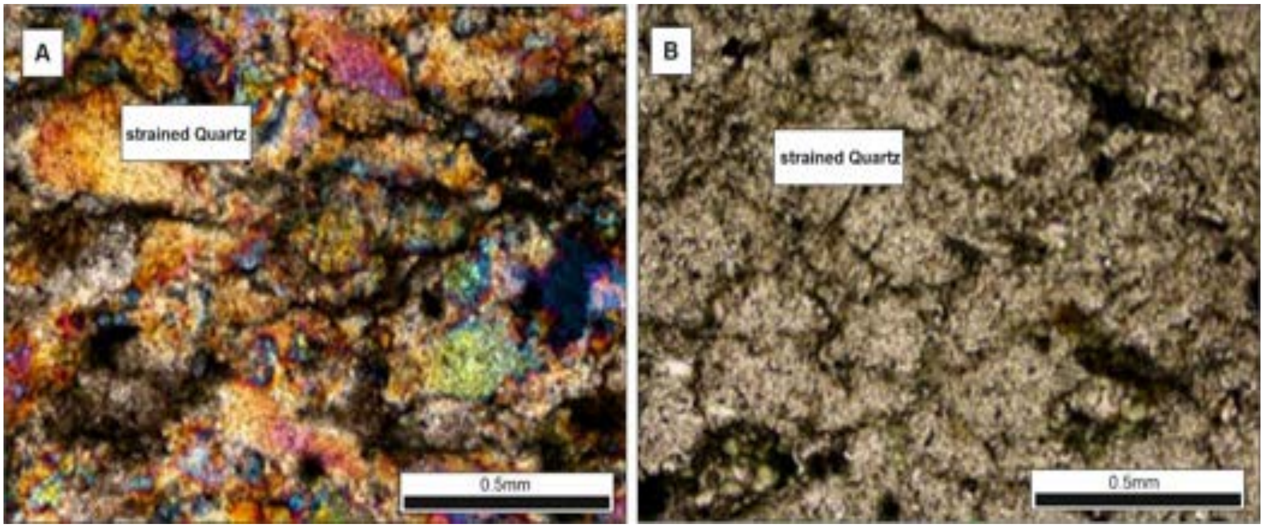

Fig. 19: Photomicrograph of Bata Quartzite, (A) Cross Nicol and (B) PPL photographs showing fractured strained quartz.

Lawat Amphibolite: The Lawat amphibolite contains quartz content 21% to 25%, needle shape Amphibole Inosilicates 60% to 64%, Opaque minerals like hornblende and ferrogedrite 15% to 17%. Mostly minerals are elongated and from front like needles (Figure 20).

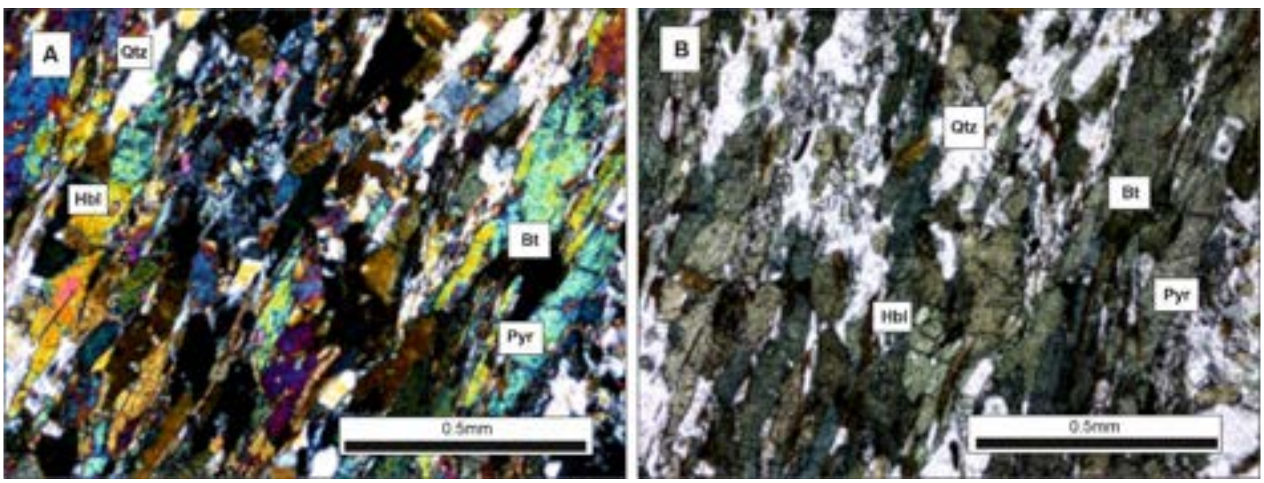

Fig. 20 : (A) cross Nicol, (B) plane polarized light (PPL) showing mineral assemblage and foliated fabric in Lawat Amphibolite. Observed minerals include Quartz (Qtz), Biotite (Bt), Hornblende (Hbl) and Pyroxene (Pyr).

Changan Marble: The Changan Marble contains calcite content 93% to 95%, quartz 3% to 5%, altered feldspar 1% to 2%. Petrographic study of this rock shows mosaic texture (Figure 21).

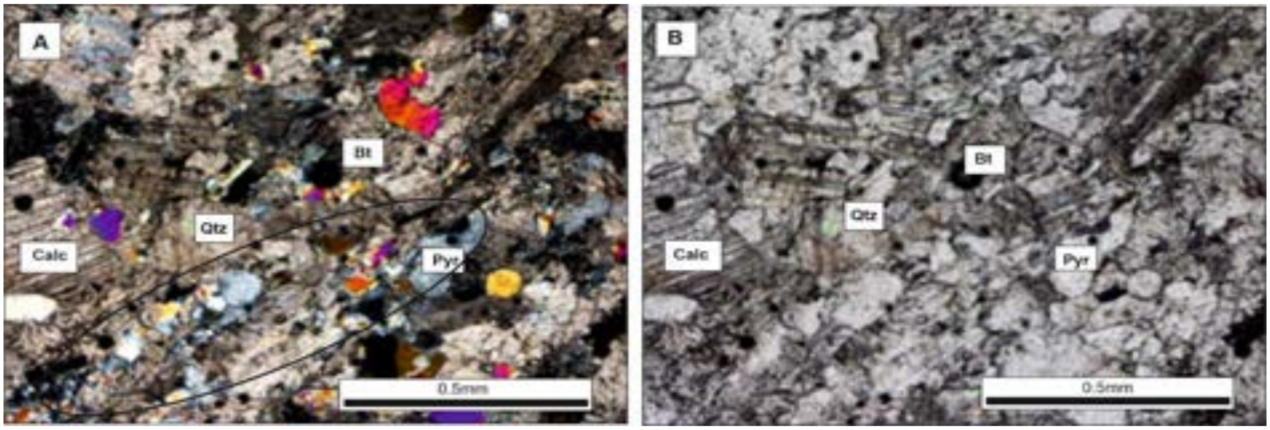

Fig. 21 : (A) Cross Nicol, (B) plane polarized light (PPL) showing mineral assemblage and inter-granular texture as circled in (A) in Changan Marble. Observed minerals include Quartz (Qtz), Calcite (Calc), Pyroxene (Pyr) and Biotite (Bt).

DISCUSSION AND CONCLUSION

The selection of durable and cost-effective materials is fundamental to successful project construction and financial control. A proven strategy for this is to evaluate the suitability of locally exposed rock, which offers considerable savings in time and resources. In line with this approach, rock samples from the Tithwal to Kel area were gathered and analyzed at the University of Muzaffarabad's engineering laboratory. The findings demonstrate that these rocks have superior qualities, making them highly suitable for use as aggregate in construction. Consequently, employing these local materials can result in significant cost and time efficiencies for projects in the region.

The average results indicate of these rock are as follow Jura granite has specific gravity value 3.94 g/cm3, water absorption 0.41%, unit weight 1.74 g/cm3, UPV 32 hertz, UCS 67.05 MPa, AIV 13.9%, LAAV 34.83%, and Schmidt rebound value 41.67 Nm these values are more than enough to prove the durability of Jura granite and petrography results also shows normal results so this expose rock is suitable for aggregate uses. Danjar granitoid has specific gravity value 2.45 g/cm3, water absorption 0.36%, unit weight 1.81 g/cm3, UPV 47.07 hertz, UCS 89.64 MPa, AIV 12.8 %, LAAV 33.26%, and Schmidt rebound value 44.66 Nm. All the values lie within the ASTM limits. Based on these results, petrography results a field observations, Danjar granitoid is also more than suitable for the construction purposes. Keran granite has specific gravity value 4.31 g/cm^3, water absorption 0.34%, Unit weight 1.84 g/cm^{3,} UPV 30.07 hertz, UCS 121.20 MPa, AIV 13.97 %, LAAV 30.36% and Schmidt rebound value 46.33 Nm. Keran Granite has all values that lies in the ASTM standards and petrography reults also doesn't shows any anomaly so Keran granite is suitable and can be used as aggregate in construction projects in place of other not available materials. Kel granite gneiss has Specific gravity value 3.70 g/cm^3, water absorption 0.42%, unit weight 1.73 g/cm^{3,} UPV 25.9 hertz, UCS 100 MPa, AIV 14.46 %, LAAV 37.2% and Schmidt rebound value 46 Nm. Based on the combain results of mechanical, field observations and petrography Kel granite gneiss has the in range values and these values assure that the rock suitable for construction purpose.

Athmuqam quartzite values are range from Specific gravity value 5.77 g/cm^3, water absorption 0.19%, Unit weight 2.3 g/cm^{3,} UPV 25.9 hertz, UCS 70.07 MPa, AIV 7.83 %, LAAV 28.04 %, Schmidt rebound value 50.33 Nm. Athmuqam Quartzite is mainly composed of 97 to 98% of quartz grains and, based on these both mechical and minerlogical assessment results, mechanical properties shows that Athmuqam quartzite is suitable for the construction purposes but due to the presence of quartz which is reactive to alkali silica reaction and if this reaction occur it will form a gel like substance that can absorb water and expand, when this gel expands this can cause cracking in the cement (Thomas and Folliard 2013[16]). Because of this expansion and cracking using Athmuqam quartzite in construction is bit risky and if used should be used with precautions. Banchattar quartzite has specific gravity value 5.49 g/cm^3, water absorption 0.21%, unit weight 2.3 g/cm^{3,} UPV 25.63 hertz, UCS 76.68 MPa, AIV 8.2%, LAAV 30.4% and Schmidt rebound value 49.33 Nm. On field hand specimen and petrography studies of Banchattar quartzite shows that quartz is abundant mineral present (98 to 99%) and presence of quartz can affect the physical and mechanical properties of the rock. Based on above stated results, according to the geotechnical test values Banchattar quartzite is suitable for the construction purposes but petrography of rock shows it contains quartz which is reactive to alkali content present in cement and and can initiate the alkali silica reaction causing trouble for the engineers so it shouldn't be used on first priority if other material is easily accessible. Bata quartzite has specific gravity value 3.70 g/cm^3, water absorption 0.16%, Unit weight 2.3 g/cm^{3,} UPV 22.56 hertz, UCS 87.73 MPa, AIV 7.33 %, LAAV 22.3 % and Schmidt rebound value 46 Nm. Based on above stated geotechnical results, Bata quartzite is suitable for the construction purposes but petrographic studies of rock shows that this rock contains quartz (98 to 99%) in abundance and the range is more than enough to reject or limit the use of Bata quartzite if the other rocks and accessible for the use. Lawat amphibolite has specific gravity value 3.23 g/cm^3, water absorption 0.25%, unit weight 2.22 g/cm^{3,} UPV 30.23 hertz, UCS 69.7 MPa, AIV 18.36%, LAAV 24.34 % and Schmidt rebound value 43.66 Nm. On the basis of above mentioned results and field observations and petrographic studies, Lawat Amphibolite is suitable for the construction purposes. The Changan marble, has specific gravity value 2.53 g/cm^3, water absorption 0.57%, unit weight 2.48 g/cm^{3,} UPV 37.36 hertz, UCS 52.66 MPa, AIV 22.47%, LAAV 38.4 % and Schmidt rebound value 40.33 Nm. On the basis of above mentioned results, field observations and petrography results it contain 90 to 95% calcite so it's a great replacement for the limestones in the dry and non acidic area (Langer & Knepper (1998)[17]), Changan marble is somehow not suitable in the areas especially where it will be exposed to moisture, freeze-thaw cycles, or acidic conditions if used precautions should be taken.

The results concluded from this study is that we can rely on these rocks for obtaining construction material but as the petrograpu results shows due to the presence of quartz in some of the rocks it is a good practice to use these rocks when other commonly used materials are not easily accessible rocks like Juran Danger, Kel and Keran granite can be used at first priority proving both strength and cost effectives so these should be used at first priority, Granite, an igneous rock, is considered as a primary source of high-quality crushed rock aggregate due to its strong interlocking crystalline structure, which ensures high compressive strength and toughness (Smith & Collis, 2001)[18] Changan marble and lawat amphibolite should be used if the first rocks are not accessible and Athmuqam quartzite, Bata quartzite and Bancahtter quartzite should be the last priority and should be use with great precautions to limit the alkali silica reaction. To limit the ASR reaction while using rock that have high silica (quartz) content a combination of supplementary cementitious materials (SCMs) like fly ash or slag cement is used to limit the alkali content of the cement Haugen, M. (2010)[19] but this is a lengthy and expensive process.

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