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Physical Properties, Strength and Durability of Selected Rocks from the Central Nepal Lesser Himalaya, Malekhu River Area for Building Stones

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Abstract

Strength and durability are crucial factors for the selection of rocks for building stones. This paper focuses on the study and evaluation of rocks of the Lesser Himalaya based on their physical properties, strength and durability. Nine different sites were selected for sampling appropriate rock types for building stones. Physical properties such as water absorption value, dry density, bulk specific gravity, saturation coefficient, porosity were determined. For mechanical strength, point load test and for chemical properties acid immersion test, salt crystallization test, methylene blue adsorption test and ethylene glycol soak test were carried out. Rocks of quartzite, granite, marble and dolomite showed higher strength values whereas rocks of quartzite, amphibolite and augen gneiss showed lower strength value. However, in terms of durability almost all rocks showed promising results except for carbonate rocks, i.e., marble and dolomite. Therefore, marble and dolomite are suitable for only interior uses such as wall cladding and interior flooring. Granite, metasandstone and quartzite with spaced foliation are suitable for dimension stones for both exterior and interior uses. Augen gneiss, amphibolite and quartzite with low strength and high durability are suitable for interior use only. From the evaluation, most of rocks showed suitable results regarding durability test.

Keywords: Physical properties; Strength; Durability; Building stone; Lesser Himalaya.

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1. Introduction

Physical properties, strength and durability are indispensable properties that help to evaluate the rocks for various applications. These properties are mandatory in characterizing natural building stones. Determination of these properties is of prime importance when deciding suitability of rocks for use under various environment and stress conditions [1:506]. Generally, durability and strength of rocks help to categorize various rock types and find their suitable end uses especially for building stones. Strength is the ability of a material to resist deformation induced by external forces, whereas durability of building stones is the measure of ability of stones to endure and maintain their distinctive characteristics of strength and resistance under its working conditions to cyclic variations of temperature, moisture content, and chemical environment [2]. Physical properties of rocks are the fundamental properties, which influences strength and durability [3:14, 4:257-258, 5:30, 6:44-45]. The amount of water absorbed by a stone can be indicated by porosity and saturation coefficient [6:45]. Pore size may also influence the durability as those with fine pores tend to be less durable compared to those with coarse pores [6:44]. Durability of building stones depends chiefly on effective porosity, water absorption, saturation coefficient, and strength, which indirectly influence resistance of rock materials to crystallization pressure [7:113]. Salt crystallization being the powerful weathering agent limits the durability of porous building stones [8:313]. High strength stones are more durable but may decrease with weathering pattern [3:16]. Strength and durability of each rock types can differ due to variation in their composition, physical properties, strength and resistance to weathering [1:506-513, 3:14-16, 7:113-127].

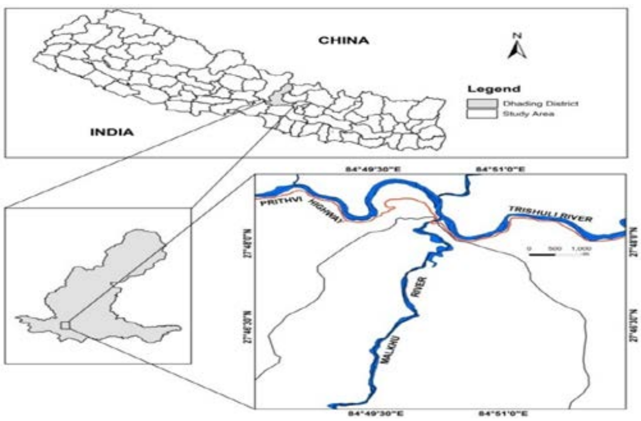

Figure 1: Location map of the study area

The Malekhu River area is a hilly region of the Lesser Himalaya (Figure 1). It is one of the promising areas, where NW-SE trending rock units composing metamorphic, igneous and meta-sedimentary rocks, distribute pervasively across the Malekhu River. Present study intends to characterize the rock materials based on some physical properties, strength and durability, which are often considered fundamental for evaluating rocks for various building stones.

2. Methodology

Reconnaissance survey was undertaken using 1:25,000 scale maps to assess geological parameters and rock mass conditions of the probable rock types including weathering grade, orientation of joint sets, joint spacing, joint size and shape. Nine different sites were selected to explore the rock mass and study their geology, rock mass characteristics and discontinuity. Rock mass characterization included Rock Mass Rating system (RMR) following [9:51-58]. Joint sets signifying the actual block shape, size and volume were determined following [10, 11]. About 10 kg of samples were collected from each of the nine study sites for laboratory analyses of petrography, physical properties, strength and durability. Rock samples taken from field was found to be slightly weathered after digging few centimeter. Study of rock thin-sections comprised of studying composition and texture of rocks under a polarizing microscope. Physical tests were made for prepared test samples. Water absorption value (WAV) and bulk specific gravity (G) were determined using core samples based on [12]. The samples were immersed in water for 48 hours, surface dried, weighed and calculated the percent of absorption. For G, samples were suspended in the distilled water and then weighed. Finally, WAV, G and dry density were determined and computed as:

$$WAV = \{W_1 - W_0/W_0\} \times 100\ \% \qquad (1)$$

Where, W_0 is weight of oven-dried sample (gm), and W_1 is weight of wet sample after soaking (gm).

$$G = \{W_0/\ (W_2 - W_4)\} \qquad (2)$$

$$Dry\ density = W_0/V \qquad (3)$$

Where, W_0 is weight of oven-dried sample, W_2 is weight of the saturated surface dried specimen in air (gm), W_4 is weight of the soaked specimen in water (gm), and V = volume of a core sample. Porosity and saturation coefficient were determined for the core samples based on [6:83]. For porosity, core samples were dried (103^{0}C) and then cooled in a vacuum desiccator at about 20^{0}C. Then, the samples were saturated with water to restore atmospheric pressure. The saturated samples were weighted in water (W_4 gm) and in air (W_5 gm), respectively. Then the samples were dried for 16 hours and then weighed (W_6 gm). Finally, the specimens were immersed in water for 23 hours and again weighed (W_7 gm). Porosity and saturation coefficient were computed using the following relations:

$$\text{Porosity } (n) = \{(W_5 - W_6)\}/\ \{W_5 - W_4)\} \times 100\ \% \qquad (4)$$

$$\text{Saturation coefficient } (SC) = \{(W_7 - W_6)\}/\ \{W_5 - W_6)\} \qquad (5)$$

Point-load strength index test was carried out for lump samples in accordance with [13]. The test was carried out in less number of samples then it is required. During this test, the irregular lump samples were inserted in the testing machine and then load was steadily increased within the 10–20 s, where the failure load was recorded as P (Kilo newton) and the distance between cones were recorded as D' in mm. The point-load strength index, Is was obtained as:

$$I_s = P/D_e^2 \qquad (6)$$

Where, De^2 *for lump tests* $= 4(W \times D') / \pi \ (mm^2)$ (7),

and W and D' are respectively, the average width (mm) of the sample and distance (mm) between the cones at failure of the sample. The size corrected point-load strength index, ($I_{s(50)}$) was obtained as:

$$(I_{s(50)}) = F \times I_s \quad (8)$$

Where, size correction factor $F = \sqrt{(D_e/50)}$ (9).

From size corrected point-load strength index value, unconfined compressive strength value was determined using the empirical relations:

For metasandstone [14]; $UCS = 21.27 \ I_{s(50)}$ (10)

For granite [15]; $UCS = 10.91 \ I_{s(50)} + 49.03$ (11)

For other rocks [16], with porosity > 1 %; $UCS = 24.83 \ I_{s(50)} - 39.64$ (12)

and with porosity < 1 %; $UCS = 10.22 \ I_{s(50)} + 24.31$ (13)

Acid immersion test (AIT) was carried out following [6:85]. In this, cubic samples of size 4×4×1.5 cm^3 were prepared and immersed in 200 ml solution of sulphuric acid solution. They were left for 10 days and then any changes taken place on the surface of the samples was noted. Crystallization test (CT) was carried out following [6:84], in which cubic samples of 4×4×4 cm^3 were prepared and their dry weights were noted as (W_1). The samples were then covered with sodium sulphate solution for 4 hours. Then the cubes were oven dried for about 18 hours and were weighed (W_2) again after cooling for about half an hour. The procedure was repeated for 15 cycles. The mean percentage weight loss under crystallization test was obtained as:

Mean % weight loss = Total % wt. loss/No. of cycles (12)

Methylene blue adsorption test was conducted following [17]. A test sample of 1 gm of size 75 µm was dispersed in 30 ml water then titrated by adding 0.5 ml methylene blue solution. After each addition, the suspension was agitated for one minute and a drop removed with a glass rod was spotted onto a filter paper. This procedure was repeated until a pale hallo was seen to have formed when the filter paper was held up to daylight. The methylene blue adsorption value (MBAV) was calculated as:

$$MBAV = \{(0.1 \times V)/M\} \times 100 \ \% \quad (13)$$

Where, V is the total volume of the methylene blue solution (in ml) added to suspension to reach end-point, and M is the test portion in grams. Ethylene glycol soak test was made following [18:287-302] to measure weatherability of stones. Here, 3× 3 ×3 cm^3 cubic samples were soaked in ethylene glycol solution for 30 days and were noted day to day for any change in degree of disintegration at a time when the worse condition occurs. The ethylene glycol soak test index (EGSTI) values were determined by adding degree of disintegration with time, where index value ranges from 2 to 10, respectively.

3. Geological settings

The Malekhu River flows from the South to the North across the geological units, and is a sixth order river. The author in [19:9-22] categorized the Lesser Himalaya of central Nepal into the Nawakot complex and the Kathmandu Complex which are separated by the Mahabharat Thrust (MT).

Table 1: Stratigraphic columns of Lesser Himalayan Rock units (After Stöcklin, 1980)

Unit		Formation	Main Lithology	Apparent Thickness (m)	Age
Kathmandu Complex	Phulchauki Group	Godavari Limestone	Limestone, dolomite	300	Devonian
		Chitlang Formation	Slate	1,000	Silurian
		Chandagiri Limestone	Limestone	2,000	Cambro–Ordovician
		Sopyang Formation	Calc-phyllite, slate	200	Cambrian
		Tistung Formation	Metasandstone, phyllite	3,000	Late Precambrian
	Bhimphedi Group	Markhu Formation	Marble, schist	1,000	Late Precambrian
		Kulikhani Formation	Quartzite, schist	2,000	Precambrian
		Chisapani Quartzite	White quartzite	400	Precambrian
		Kalitar Formation	Schist, quartzite	2,000	Precambrian
		Bhainsedobhan Marble	Marble	800	Precambrian
		Raduwa Formation	Garnetiferrous schist	1,000	Precambrian
Mahabharat Thrust (MT)					
Nawakot Complex	Upper Nawakot Group	Robang Formation	Phyllite, quartzite	200 – 1,000	Paleozoic
		Malekhu Limestone	Limestone, Dolomite	800	Paleozoic
		Benighat Slate	Slate, argillaceous dolomite	500 – 3,000	Paleozoic
	Lower Nawakot Group	Dhading Dolomite	Stromatolitic dolomite	500 – 1,000	Late Precambrian
		Nourpul Formation	Phyllite, quartzite, dolomite	800	Late Precambrian
		Dandagaon Phyllite	Phyllite	1,000	Late Precambrian
		Fagfog Quartzite	White quartzite	400	Late Precambrian
		Kuncha Formation	Phyllite, quartzite, Conglomerate, gritstone	5,000	Late Precambrian
Main Boundary Thrust (MBT)					
Siwalik Group			Conglomerate, sandstone, mudstone,	Several Kilometers	Neogene

The MT lies at the northern part of the study area and trends NW-SE across the Malekhu River area. The study area comprises the upper two formations of the Upper Nawakot Group, i.e. the Malekhu Limestone and the Robang Formation, and the Bhimphedi Group comprising of six formations, and the lower part of the Phulchauki Group (the Tistung Formation) of the Kathmandu Complex (Figure 2; Table 1). These units extend NW-SE and distributes throughout the Malekhu River watershed. The granitic intrusion exists at the core of the huge syncline, of which the present study area covers the part of the northern limb of the syncline. Limestone with grey phyllite, sericite quartzite, quartzite, amphibolite and schist are the major rock types in the Upper Nawakot Group. Garnetiferous schist, dark grey quartzite, crystalline marble, white quartzite, augen gneiss, schist, metasandstone, granite are the major rock types of the Bhimphedi Group and lower part of the Phulchauki Group.

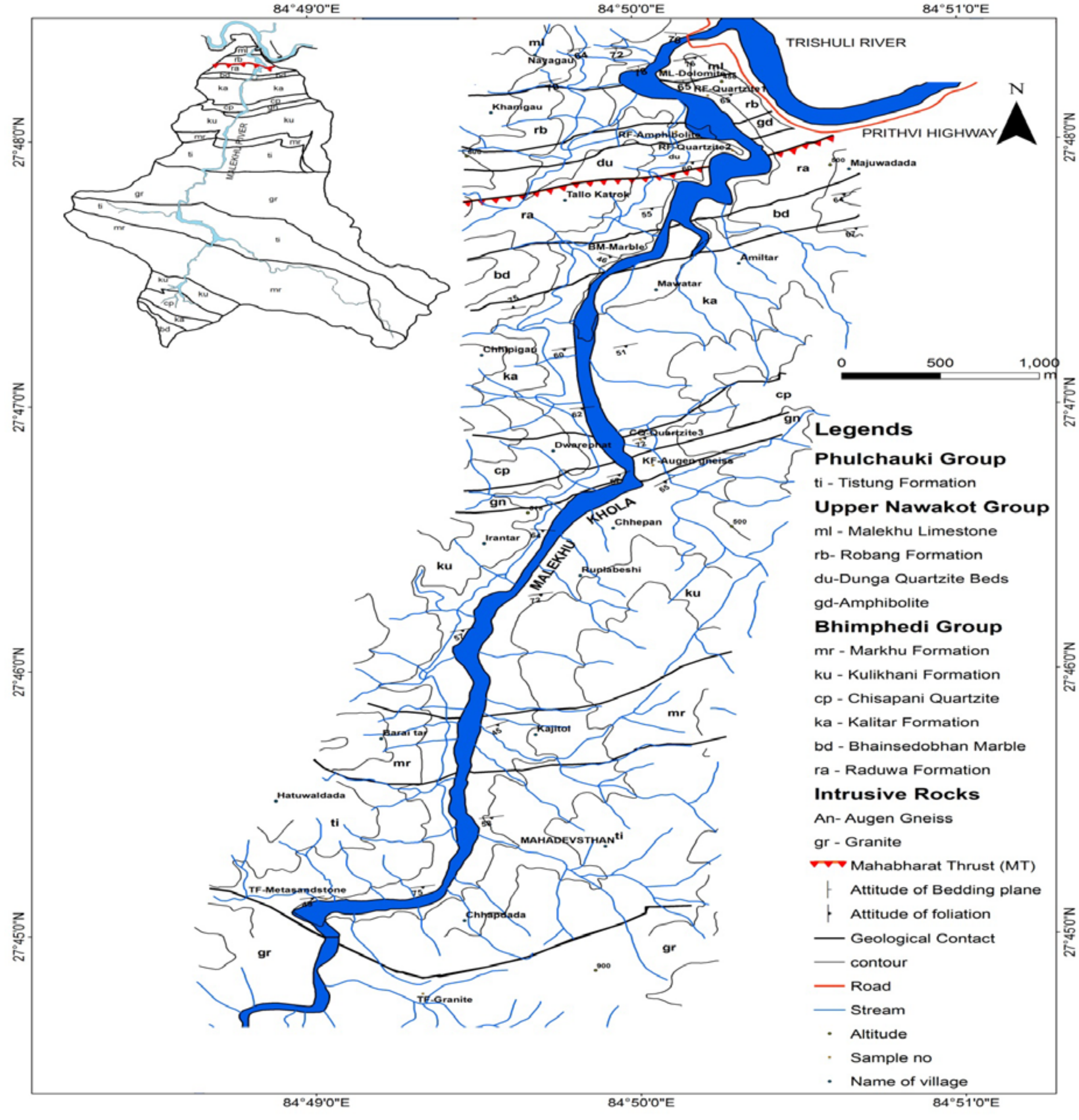

Figure 2: A geological map of the Malekhu River Area showing sample sites

4. Results

Nine rock samples were separated into six categories based on their textural and structural characteristics. These are:

- Finely crystalline argillaceous dolomite (ML-Dolomite2) and laminated fine- to medium-grained metasandstone (TF-Metasandstone)
- Foliated, medium to coarsely crystalline, white to light grey quartzite (RF-Quartzite1, RF-Quartzite2 ,CQ-Quartzite3)
- Foliated, medium crystalline and green amphibolite (RF-Amphibolite)
- Coarsely crystalline and dark grey Augen gneiss (KF-Augen gneiss)
- Massive, coarsely crystalline white marble (BM-Marble), and
- Massive, coarsely crystalline granite (TF-Granite).

4.1. Rock mass characteristics and discontinuity

RF-Quartzite2 and TF-Metasandstone fall in fair category of rock mass class (Table 2). KF-Augen gneiss falls in very good category. Remaining rock samples are of good rock types. The block sizes of the rock samples (V_b) range from 0.1 to 12.7 m^3. The block shape factor (β) varies from 21.7 to 124 (Table 2). Therefore, the block forms are compact, long, flat and both. The Block Quality Designation (BQD) value ranges from very poor to good.

Table 2: Field descriptions of nine rock samples, rock mass characteristics, joint density, joint shape and volume.

Sample	Formation	Location	RMR category	*[1]JD 1/m	*[2]Vb m³	BSF *[3]β	Block type	*[4]BQD %
ML-Dolomite	Malekhu limestone	27°48'19"N 84°49'58"E	68 Good rock	18	5.67	22	Long and flat	Very poor
RF-Quartzite1	Robang Formation	27°48'11"N 84°50'04"E	67 Good rock	30	0.56	37	Flat	Very poor
RF-Amphibolite	Robang Formation	27°48'04"N 84°50'07"E	74 Good rock	11	4.11	27	Compact	Good
RF-Quartzite2	Robang Formation	27°47'56"N 84°50'12"E	56 Fair rock	37	0.8	28	Compact	Very poor
BM-Marble	Bhaisedobhan Marble	27²47'50"N 84°49'59"E	74 Good rock	14	1.26	75	Flat	Poor
CQ-Quartzite3	Chisapani Quartzite	27°46'51"N 84°49'50"E	72 Good rock	16	0.1	124	Long	Very poor
KF-Augen gneiss	Kulikhani Formation	27°46'43"N 84°49'50"E	81 Very good rock	4.3	12.68	29	Compact	Good
TF-Meta sandstone	Tistung Formation	27°44'53"N 84°48'50"E	60 Fair rock	7.7	2.25	39	Flat	Poor
TF-Granite	Tistung Formation	27°44'47"N 84°49'08"E	74 Good rock	11	0.23	32	Compact	Fair

Rock mass determined from total rating: VGR = Very Good Rock, GR = Good Rock, FR = Fair Rock [9], *[1]JD = Joint density (per frequency 1/m), (BV) Block volume (*[2]Vb) = S1×S2×S3/(Sinγ1×Sinγ2×Sinγ3) (S1, S2 & S3 are the maximum, intermediate and minimum joint spacing in meters, γ1, γ2 & γ3 are intersection angles between these major joint sets obtained through stereographic projection), (BSF) Block shape factor (*[3]β) = $(\alpha2+\alpha2\times\alpha3+\alpha3)^3/(\alpha2\times\alpha3)^2$ (α2 = S2/S1 and α3 = S3/S1) , *[4]BQD% = {(∑LSC>1m)/Ltsc}×100% ∑LSC>1m, summation of scan line length of joint sets more than 1 m and Ltsc is the total length of scan line (Very good = 90-100%, Good = 75-90%, Fair = 50-75%, Poor < 25 % [11:29].

4.2. Microscopic level description

Fine-grained siliceous dolomite has higher proportion of calcite and dolomite. Metasandstone has higher proportion of recrystallized quartz and randomly oriented mica minerals (Figure 3, Table 3). Light grey, fine- to medium-grained quartzite samples (RF-Quartzite1, RF-Quartzite2 and CQ-Quartzite3) have similar modal composition of quartz grains (Figure 4, 5 and 6). However, RF-Quartzite1 sample has coarser grain size and has higher percentage of sericite minerals compared to that in two other quartzite samples (Table 3). Foliation in RF-Quartzite1 is continuous while that in other two samples is spaced. Mineral grains of calcite and quartz grains are homogenous in dolomite and quartzite, respectively. Beside these samples, other samples have heterogeneous mineral grains. Massive and randomly oriented minerals occur in the samples of RF-Amphibolite, BM-Marble (Figure 7) and TF-Granite.

Table 3: Field description of nine different rock types and their microscopic description

Sample	Formation	Mineralogical Description	Composition	Rock type
ML-Dolomite	Malekhu limestone	Light grey, medium grained, laminated	Calcite & dolomite, quartz, feldspar, biotite, muscovite	Dolomite
RF-Quartzite1	Robang Formation	White, coarsely crystalline	Quartz, sericite, feldspar, biotite, muscovite	Sericite Quartzite
RF-Amphibolite		Green, medium-coarse grained, foliated	Amphibolite, quartz, feldspar, biotite, muscovite	Amphibolite
RF-Quartzite2		Light grey, coarse grained, lamina and foliated	Quartz, feldspar, biotite, muscovite, sericite	Quartzite
BM-Marble	Bhaisedobhan Marble	White, medium-coarse, crystalline, slightly weathered	Quartz, feldspar, biotite, muscovite, calcite & dolomite	Marble
CQ-Quartzite3	Chisapani Quartzite	Light grey, coarse grained, foliated, porphyroblastic	Quartz, feldspar, biotite, muscovite, chlorite	Quartzite
KF-Augen gneiss	Kulikhani Formation	Light grey, coarse grained, foliation present, porphyroblastic, gneissosity	Quartz, feldspar, biotite, muscovite, sericite	Augen gneiss
TF-Metasandstone	Tistung Formation	Light grey, coarse grained, porphyroblastic, foliated, lamina present	Quartz, feldspar, muscovite, sericite, chlorite	Meta-sandstone
TF-Granite	Tistung Formation	Light grey, coarsely crystalline, randomly oriented minerals.	Quartz, feldspar, muscovite, biotite, muscovite, sercite	Granite

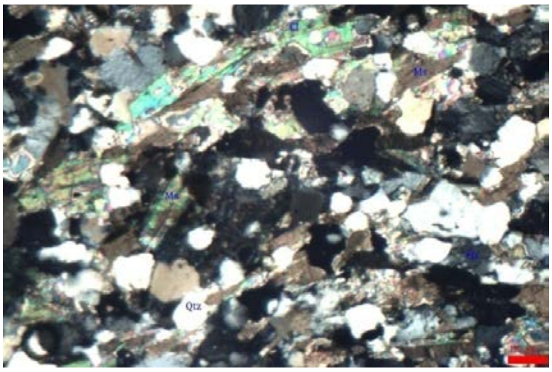

Figure 3: Detrital quartz grains and slightly oriented mica grains showing in metasandstone (TF-Metasandstone)

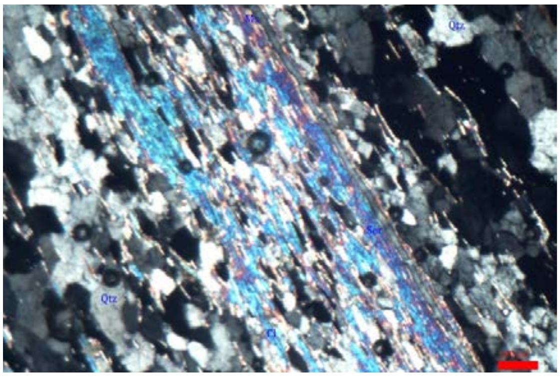

Figure 4: Preferred orientation of muscovite, sericite and chlorite grains in sericite quartzite (RF-Quartzite1)

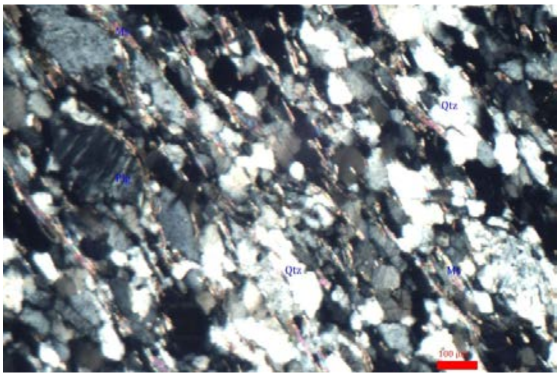

Figure 5: Slightly foliated quartzite (RF-Quartzite2)

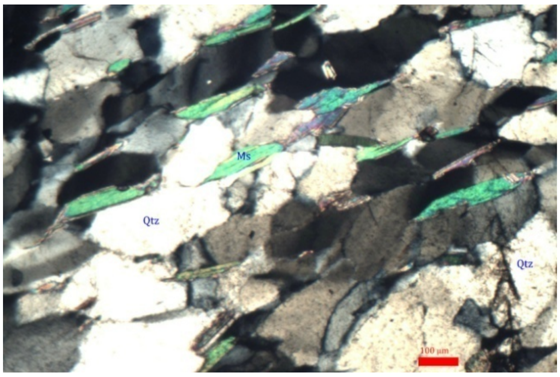

Figure 6: Recrystallized quartz grains and preferred orientation of muscovite showing in quartzite (CQ-Quartzite3)

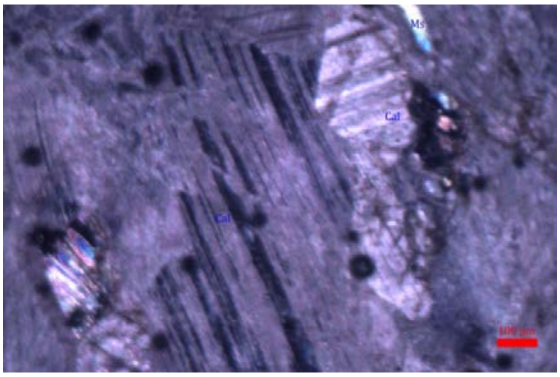

Figure 7: Coarsely crystalline calcite grains showing in marble (BM-Marble)

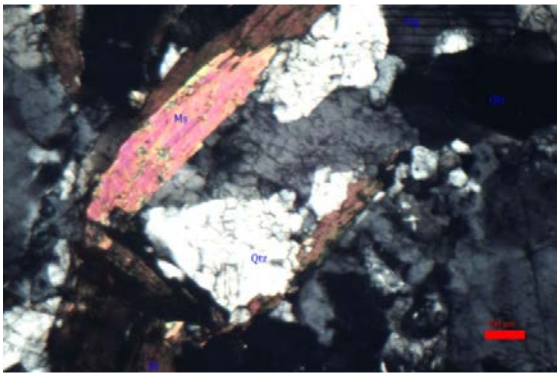

Figure 8: Coarsely crystalline mineral grains of augen gneiss (KF-Augen gneiss)

KF-Augen gneiss is coarse-grained and having augen shaped feldspars and large quartz grains with distinct gneissosity developed by micas (Figure 8). Samples of dolomite, quartzite, and augen gneiss exhibit higher packing density compared to other rock samples.

4.3. Physical properties

Water absorption and bulk specific gravity vary from 0.35 to 2.24 % and from 2200 to 3200 kg/m³, respectively. The lowest water absorber among the rock sample is of augen gneiss and granite while the highest one is the sample of amphibolite. Dry density of different rock types ranges from 2.5 to 2.75 kg/m^3.

The water absorption and dry density of the rocks quartzite, marble, dolomite and granite satisfy with ASTM standard for the building stone. Porosity is low (<2%) in quartzite samples of the Robang Formation (RF-Quartzite1 and RF-Quartzite2) and the Chisapani Quartzite (CQ-Quartzite3). The samples augen gneiss (KF-AG) and marble (BM-Marble) have the porosity exceeding 2 %.

The saturation coefficient ranges from 0.1 to 0.9 % (Table 4). The sample ML-Dolomite, CQ-Quartzite3 and TF-Granite have more than or equal to 0.8 % saturation coefficient indicating that these samples have potential towards frost damage and low durability [6:45].

4.4. Strength

Point-load strength index value ranges from 1.31 Mpa (KF-AG) to 8.11 Mpa (ML-Dolomite) (Table 4). Among six categories, the first (dolomite and metasandstone) and the third rock types (RF-Quartzite2 and CQ-Quartzite3) have higher point load strength indices, which range from 6.06 to 8.11 Mpa, compared to the other categories of rocks.

The point-load strength index is moderate in samples of sericite quartzite (RF-Quartzite1 ii-type), amphibolite (iii-type) and granite (vi-type) ranging from 2.37 to 3.78 Mpa. Metasandstone (TF-Metasandstone) shows the highest UCS (128.9 Mpa) whereas augen gneiss (KF-Augen gneiss) gives the lowest UCS value (37.67 Mpa) (Table 4). Dolomite (ML-Dolomite) and quartzite's (RF-Quartzite2& CQ-Quartzite3) have moderate UCS. However, sericite quartzite (RF-Quartzite1) of the Robang Formation possesses lower UCS value in comparison to other quartzite samples.

4.5. Durability

In acid immersion test, samples BM-Marble and ML-Dolomite show severe and mild sign of decay, respectively (Table 4). In addition, rest of other samples show low sign of decay. From the crystallization test, the mean weight loss of all rock specimens varies from 0 to 1% indicating grade A category or most durable rocks [24] (Table 4).

The MBAV varies from 0.44 to 0.89 % and most of the samples have less than 1% indicating that the clay material or swelling material is relatively negligible in them. Therefore, swelling potentiality of samples is very low [17]. Ethylene glycol soak test shows that soak test index is 2.0 in all samples indicating that they are chemically durable and well resistant against weathering [25:68-71].

Table 4: Evaluation of rock masses based on durability and strength of selected rock types

Sample	Rock types	Physical properties					Strength		Durability			
		*[1]WAV, %	G, kg/m³	*[2]Dry Density, kg/m³	n, %	SC	$I_{s(50)}$, Mpa	*[3]UCS, Mpa	AIT	*[4]CT, %	MBAV, %	*[5]EGSTI
ML-Dolomite	Dolomite	0.88	2.5	2.75	1.5	1	8.11	107	[a]MSD	0.51 (A)	0.5	2.0
RF-Quartzite1	Sericite Quartzite	0.97	2.6	2.49	1.5	0	2.37	49	LSD	0.01 (A)	0.44	2.0
RF-Amphibolite	Amphibo-lite	2.24	3.2	2.76	1.6	0	3.78	63	LSD	0.1 (A)	0.87	2.0
RF-Quartzite2	Quartzite	1.11	2.4	2.42	0.5	0	6.07	111	LSD	0.1 (A)	0.78	2.0
BM-Marble	Marble	0.88	2.3	2.79	2.6	0	1.54	40	SSD	0.15 (A)	0.61	2.0
CQ-Quartzite3	Quartzite	1.55	2.5	2.9	0.2	1	6.16	113	LSD	0.01 (A)	0.67	2.0
KF-Augen gneiss	Augen gneiss	1.3	2.5	2.6	2.3	0	1.31	38	MSD	0.03 (A)	0.87	2.0
TF-Meta sandstone	Metasand-stone	0.35	2.2	2.5	0.4	1	6.06	129	MSD	0.77 (A)	0.87	2.0
TF-Granite	Granite	0.38	2.5	2.56	0.8	1	4.88	102	MSD	0.13 (A)	0.89	2.0

*[1]WAV (0.2 to 8 % [20-23], *[2]Dry density (ASTM , ranging from 1.76 to 2.8 kg/m3 [20-23]; *[3]UCS (12 to 138 Mpa [20-23]),*[4]CT = Crystallization test [grading: A (<1 %), B (1-5 %), C (5-15 %), D (15-35 %), E (35-100 %), F (> 100 %) % wt. loss after [24], *[5]EGSTI (ranges from 2; rock material is more or less unaffected to 11; rock material totally broken down [25:69-70]); [a]MSD = mild sign of decay, LSD = low sign of decay, SSD = severe sign of decay.

5. Discussions

Among six different categories, each rock type shows variation in strength value that ranges from medium to high strength [26]. Dolomite and quartzite samples show normal UCS value that ranges from 107.19 MPa in dolomite and 111.08 to 113.31 MPa in quartzite because of low WAV and higher density. Quartzite (RF-Quartzite2, CQ-Quartzite3), metasandstone and granite having higher resistance to load or higher strength value can be used for flooring, cladding and roofing of slabs etc [1:506]. Augen gneiss sample (KF-Augen gneiss) shows very low UCS value than that of average value ranging from 49 MPa to 196 MPa [27:6]. It is so because the micaceous minerals in rock are slightly weathered which gives space to secondary pore to develop while performing test. During the test, pores start to develop as micro-cracks and then slippage occurs along the micro-cracks [28]. In addition, it has coarse-grained texture having low amount of quartz (around 25 %) and higher WAV [3:14-16, 29:122]. Being similar composition quartzite sample RF-Quartzite1 has lower WAV and higher density but it has low UCS value. It is so because the quartzite sample has continuous foliation structure defined by a phyllo-silicate mineral, i.e. sericite. The higher content of sericite minerals and loosely interlocked quartz grain demonstrate the lower compressive strength value [29, 30]. Dolomite and marble samples have similar WAV and density value while being slightly weathered carbonate rock, BM-Marble exhibits lower strength value than that of ML-Dolomite. The normal strength value of dolomite is above 52 Mpa [21] and marble ranges from 116 to 162 Mpa [20]. TF-Amphibolite exhibits medium-grained, crystalline and interlocked fabric, higher WAV and higher porosity. Therefore, it has lower durability and moderate strength compared to other samples. Quartzite (RF-Quartzite1), amphibolite, and augen gneiss have low resistance to compressive load and are therefore suitable for interior cladding [6:42]. The point-load index value of foliated rock types are low because the foliated rock develops initial cracks while hammering and such cracks continue to develop further breakage that weakens the rocks. In terms of durability, except carbonate rocks all the samples show positive and good results. Metasandstone and dolomite exhibit higher % weight loss during crystallization test, which directly indicates that these rocks are less durable in comparison to other rock types and are susceptible to weathering [8:313]. Limestone, marble and calcareous rocks are susceptible to acid rain and not appropriate for external applications [3:22]. Except carbonate rocks, other rocks having higher durability can be used for exterior cladding of buildings particularly in polluted urban environments [6:42]. Therefore, durability is an essential parameter while considering for interior use rather than the strength.

6. Conclusions

Among six different varieties of rocks which have been studied for suitability of building stones, the suitable rock types considering strength and durability are those of ML-Dolomite (Malekhu Limestone), RF-Quartzite2 (Robang Formation), CQ-Quartzite3 (Chisapani Quartzite), and TF-Metasandstone and TF-Granite from the Tistung Formation. Majority of the rock samples, except amphibolite (RF-Amphibolite), and marble (BM-Marble), exhibit moderate range of strength value, whereas quartzite (RF-Quartzite) and augen gneiss (KF-Augen gneiss) have the least strength values though they have higher durability. Durability tests of almost all the samples except carbonate rocks show suitable results. Rock samples of quartzite, metasandstone and granite with higher strength and durability are suitable for exterior and interior purposes such as flooring, cladding, roofing as slabs etc. In addition, the samples KF-Augen gneiss, RF-Amphibolite and RF-Quartzite1 with low strength and high durability are suitable for interior flooring, facing and cladding uses, and exterior facing and cladding applications. Dolomite and marble are suitable only for interior purposes such as interior flooring and wall cladding because of low durability and moderate strength values.

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7. Recommendations

Care should be taken to minimize the formation of micro-cracking in samples while preparing samples for the tests. For strength test, core samples are better than the lump samples. In field, discontinuity analysis might help to determine tentative block shape that ultimately help to know exact size and shape of blocks. The physical, chemical and mechanical test can be used to assess preliminary investigation of rock types for building stone. Based on durability and strength, the most suitable rock type among the sample is quartzite.