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Texture and index properties of rocks from Malekhu-Thopal Khola area, Central Nepal Lesser Himalaya

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ABSTRACT

Infrastructures such as road, building, cannals, dam, bridges and so on lie on geological bases. Durability of the structures demands detail study of rocks in microscopic level. Such study helps to give knowledge about strength and physical properties of rocks, and their usefulness as construction materials. Index properties are the basic parameters to be found out before the developent of engineering structures, and are governed by the texture of the rock such as grain interlocking, crystallinity, shape factor, grain size homogeneity, grain orientation, micro fractures, etc.

Textural study of the samples gave the micropetrographic quality index ranging from 0.05 to 49, grain size homogeneity from 0.06 to 0.74, interlocking index ranging from 7 to 92% and texture coefficient ranging from 1.08-1.97. Micropetrographic index has great influence on porosity and point load strength index. Siliceous rocks having high texture coefficient are mechanically sound. When homogeneity in grain size, shape and orientation increases, texture coefficient tends to diminish. Therefore, texture coefficient is an important variable.

Dry density of samples ranges from 2309 to 3224 kg/m^3, porosity from 0.08 to 8.91% and point load index from 0.26 to 13.13 MPa. Water Absorption Value (WAV) is entirely below 2% except for the slates indicating that most of the rocks have low effective porosity. Strength of rocks varies from very low to very high. Considering the texture and index properties, the rock types suggested for the construction aggregates are quartzites of the Nourpul Formation, the Fagfog Quartzite, and the Chisapani Quartzite, and psammitic schist of the Robang Formation. The quartzite samples from the Fagfog and the Norpul Formations are useful for silica sources. Siliceous dolomite 'Np3' of the Nourpul Formation and dolomite 'Ml1' of the Malekhu Limestone also show good interlocking, high density and high strength.

Key words: Texture, grain interlocking, micropetrographic index, index properties, construction material

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INTRODUCTION

Different engineering infrastructures lie on geological bases, rock or soil. Hence, the study of geology including index properties and microfabrics is important for durable and sustainable engineering structures. Index properties of rocks such as unit weight, specific gravity, porosity and point load strength index rely on their composition and texture (Přikryl, 2006). Some parameters dealing with index properties of rocks may be clearly demonstrated by studying textures study such as grain size, grain interlocking, crystallinity, micro fractures, joints, microfoliations, porosity, grain orientation, etc. The textural characteristics such as angular grains, packing density and packing proximity appear to be more important than mineralogy for predicting engineering properties (Zorlu et al., 2004). The grain size along with porosity is the main controlling factor of rock mechanical properties of genetically and mineralogically similar rocks (Přikryl, 2001; 2006). Räisänen (2004) showed how quantitative petrography could assist to describe texture and interpret the results of mechanical tests. Smith and Collis (1993) reviewed influence of the occurrence,

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mineral composition and geological history on the engineering properties of aggregate materials. Singh and Tamrakar (2013) characterized the rock mass of Malekhu applying RMR and GSI. Tamrakar et al. (2007) correlated engineering properties with petrographic properties of sandstones and found porosity and grain interlocking to be important parameters. Several authors have studied properties of rocks and developed relations (Rigopoulos et al., 2010; Gupta and Sharma, 2012; Tandon and Gupta; 2013)

The study area is located in the Malekhu-Thopal Khola corridor, and is one of the transit points to Kathmandu (Fig. 1). The study area comprises fourteen formations having varieties of rocks, mainly low-grade to high-grade metamorphic rocks and sedimentary of the Lesser Himalaya.

GEOLOGICAL SETTING

Geology of the study area is based on the work of Stöcklin and Bhattarai (1978), Stöcklin (1980) and the present survey along the Malekhu-Thopal Khola section (Table 1; Fig. 2). Precambrian rock formations are well exposed along the Malekhu Khola and the Thopal Khola. The main lithologies are phyllite, quartzite, slate, schist, dolomite and limestone. The area is characterized by two broader complexes: the Nawakot Complex and the Kathmandu Complex. The Kathmandu Complex is a part of the Lesser Himalayan ‘crystallines’ (Bhimphedi Group) but includes fossiliferous sediments of early-Middle Paleozoic unit (Phulchoki Group) on the top, occupying the large core of the synclinorium. There is a massive granite intrusion (Agra Granite) in the Tistung Formation of the Phulchauki Group (Table 1). The Nawakot Complex includes the Lower Nawakot Group and the Upper Nawakot Group (Stöcklin and Bhattarai, 1977; Stöcklin, 1980). The Nawakot Complex consists exclusively of low-grade metasedimentary rocks. The Mahabharat Thrust passes across the Malekhu Khola separating the footwall Nawakot Complex with the hanging wall Kathmandu Complex. The dominant structural feature is the large, WNW-ESE trending Mahabharat Synclinorium, a doubly plunging megafold with steep flanks, a well-developed western closure and a narrow, elongated eastern wing. The core of the Mahabharat Synclinorium extends in WNW-ESE direction at the southern part of the Malekhu Khola Watershed.

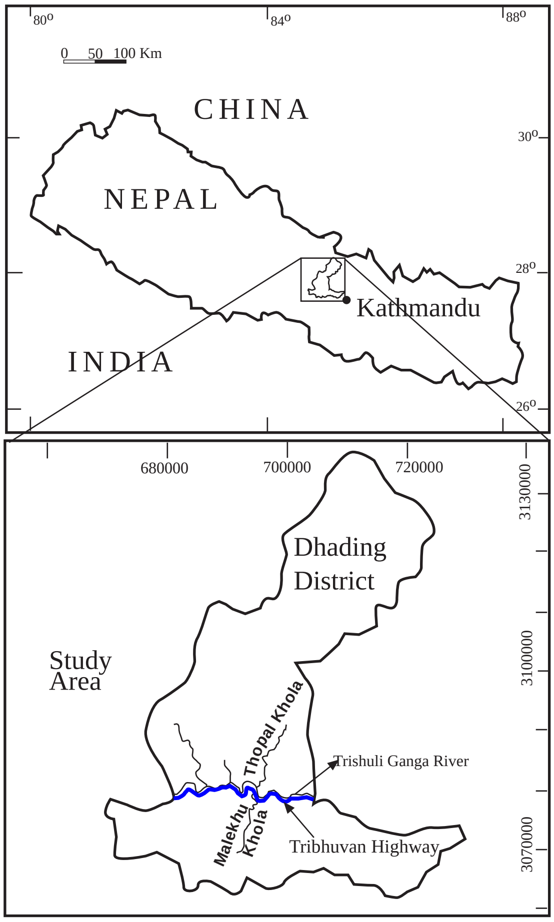

Fig. 1 Location map of the study area

METHODOLOGY

Twenty-six samples were collected from the field. Sample sites and descriptions are provided in Table 2. Thin-sections were prepared in the laboratory and test specimens were prepared to determine various textural compositional parameters and carry out physical tests.

Textural Analysis

Textural analysis (i.e. analysis of shapes and other geometrical parameters of rock-forming minerals) is of major interest for the sound petrographic interpretation of rock mechanical tests. Image analysis was done using software “Image J”. Grain area, perimeter, aspect ratio, and contact perimeter between grains were measured during the quantitative microfabric analysis of the thin section. Secondly, fabric coefficients: micro-petrographic quality index (K), “texture” coefficient (TC), index of interlocking (t) and grain size homogeneity (g) were determined.

Table 1: Stratigraphic sub-division of Central Nepal, Lesser Himalaya (After Stöcklin and Bhattarai, 1977 and Stöcklin, 1980)

Complex	Group	Formation	Main lithology	Thickness (m)	Age
Kathmandu Complex	Phulchauki	Godawari Limestone	Limestone	300-400	Devonian
		Chitlang Formation	Slate, Quartzite	1000	Silurian
		Chandragiri Limestone	Limestone	2000	Cambrian
		Sopyang Formation	Slate, calc. Phyllite	200	Cambrian (?)
		Tistung Formation	Metasandstone, Phyllite	300	Early Cambrian or Late Precambrian
	Bhimphedi	Markhu Formation	Marble, schist	1000	Late Precambrian
		Kulekhani Formation	Quartzite, schist	2000	Precambrian
		Chisapani Quartzite	White quartzite	400	Precambrian
		Katitar Formation	Quartzite, schist	2000	Precambrian
		Bhainsedobhan Marble	Marble	800	Precambrian
		Raduwa Formation	Garnetiferous schist	1000	Precambrian
……………………………….Mahabharat Thrust…………………………….					
Nawakot Complex	Upper Nawakot Group	Robang Formation	Phyllite, Quartzite	200-1000	Early Paleozoic
		Malekhu Limestone	Limestone, Dolomite	800	Early Paleozoic
		Benighat slate	Slate, argillaceous dolomite	500-3000	Early Paleozoic
			Unconformity (?)		
	Lower Nawakot Group	Dhading Dolomite	Stromatolitic dolomite	500-1000	Precambrian
		Nourpul Formation	Phyllite, Metasandstone	800	Precambrian
		DandagaunPhyllite	Phyllite	1000	Precambrian
		Fagfog Quartzite	White Quartzite	400	Precambrian
		Kuncha Formation	Phyllite, Quartzite	3000	Precambrian

Index of interlocking (g) expresses the complexity of grain-grain relationships (Dreyer, 1973). This parameter compares the area of the grain and its perimeter which connects neighbouring grains. The increasing value of this parameter indicates a higher complexity of the grains' boundaries which means that the grain boundaries are more oblate or irregular. It is computed according to:

$$g = \frac{1}{n} \sum \frac{L_{Pi}}{\sqrt{A_i}} \qquad (1)$$

where, n denotes number of grains considered, L_{Pi} is a portion of the grain perimeter which contacts neighbouring grains and A_i represents the area of exposed grain section.

Index of grain size homogeneity (t) (Dreyer, 1973) is a directionless fabric parameter describing grain size distribution in the material. Its value increases with increasing dominance of one grain size group. The maximum value is reached when the material is built up by grains of unique size. On the other hand, the 't'value rapidly decreases as soon as even few porphyry grains occur in prevalent fine-grained matrix. The index of "textural" homogeneity is calculated as:

$$t = \frac{A_{avg}}{\sqrt{\sum (A_i - A_{avg})^2}} \qquad (2)$$

where A_{avg} is the average grain cross-section (area) and A_i is the area of individual grain.

Texture coefficient (TC) was originally devised to assess the rock fabric for rock mechanics (Howarth and Rowlands, 1986). This quantitative dimensionless measure aims to analyze grain shape parameters such as circularity and elongation, orientation of grains, and degree of grain packing. The parameter is expressed by the following formula:

$$TC = AW\left[\left(\frac{N_0}{N_0 + N_1} \cdot \frac{1}{SF_0} + \frac{N_1}{N_0 + N_1} \cdot AR_1 \cdot \frac{AF_1}{5}\right)\right] \qquad (3)$$

Where AW is the grain packing weighting, N0 is the

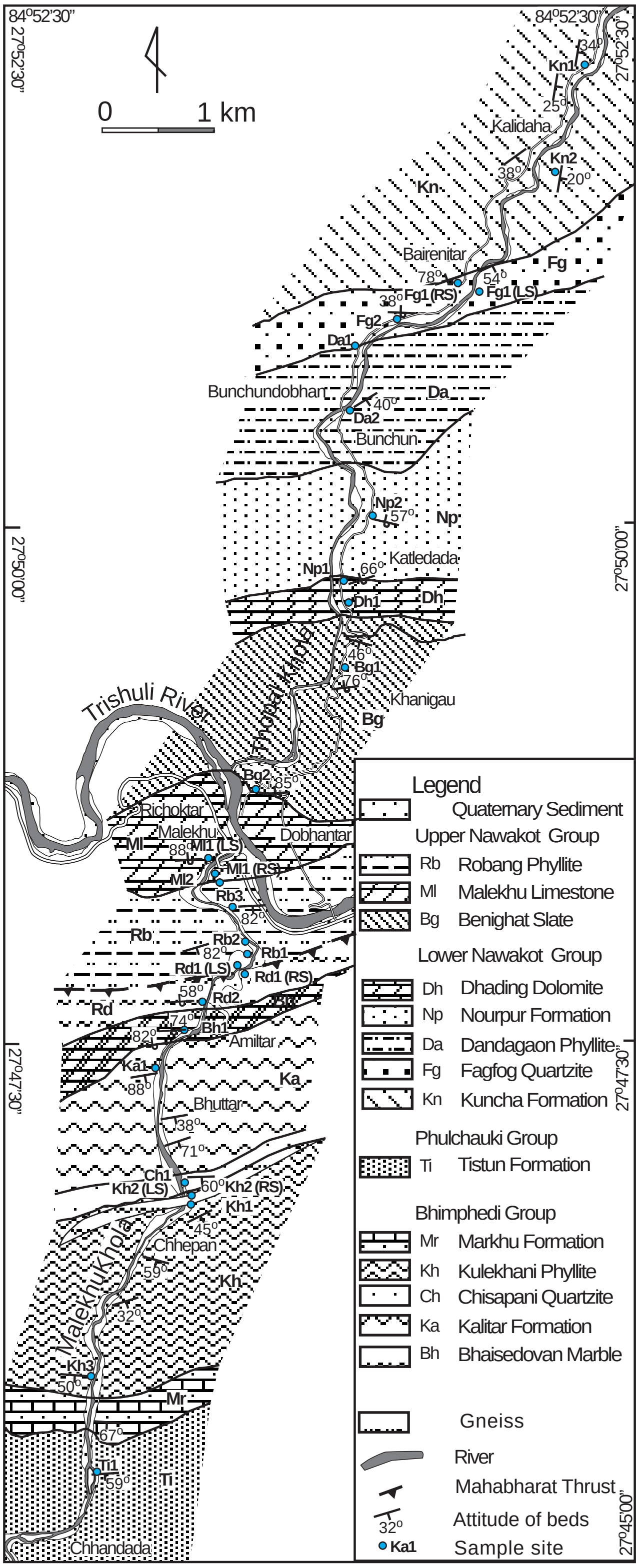

Fig. 2 Geological map of the study area

number of grains whose aspect ratio is below a pre-set discrimination level (2 in this study), N_1 is the number of grains whose aspect ratio is above a pre-set discrimination level, SF_0 is the arithmetic mean of discriminated shape factors 4.π.Area/(Perimeter)^2, AR_1 is the arithmetic mean ofdiscriminated aspect ratios of N_1 grains calculated using Major Axis/Minor Axis, and AF_1 is the angle factor, quantifying grain orientation. Grain packing AW considers intergranular space in sedimentary rocks. For igneous rocks, this term is equal to 1 (Howarth and Rowlands, 1986, 1987). AF quantifies angular orientation of grains' long axes. This term is calculated only for elongated grains (aspect ratio higher than 2). The angle factor is computed by:

$$AF = \sum_{i=1}^{9} \frac{X_i}{\left(N(N-1)/2\right)} \qquad (4)$$

Where, N is the total number of elongate particles, X_i is the number of angular differences in each class and i is the weighting factor and class number. The higher TC represents increased roughness of grain boundaries, higher elongation and higher packing density. The arithmetic mean of shape factors SF was calculated only for the grains having an aspect ratio lower than 2.0 whereas the aspect ratio AR was calculated for all particles above this level.

The assessment of rock geomechanical quality based on modal composition was made through the micropetrographic quality index (K) (Mendes et al., 1966):

$$K = \frac{\sum X_i}{\sum Y_i} \qquad (5)$$

Where X_i is the percentage of area occupied by sound minerals having favourable influence on rock mechanical properties and Y_i reflects the percentage of area occupied by altered minerals, minerals in unfavourable position (i.e. minerals exhibiting shape preferred orientation) and cracks and pores deteriorating the quality of the rock.

As a part of petrographic analysis, composition of different rock samples was studied in laboratory using a polarizing microscope.

Table 2: Showing location of sampling, lithology and degree of weathering of rock mass

Sample	Lattitude	Location	Lithology	Weathering
Kn1	N 27°52'13.7"/E 84°52'7.1"	Uphill side of the Malekhu-Dhading Besi road (MDBR) about 1 km away from Kalidaha toward Dhading Besi.	Coarse, greenish grey mylonitic schist interbedded with greenish grey metasandstone and phyllite	Slightly to moderately
Kn2	N 27°51'43.6" /E 84°51'57.8"	Left bank of Sukaurakhola about 1 km from its confluence with Thopal khola.	Thinly laminated, medium to thickly foliated, greenish grey phyllite with some quartz veins	Moderately
Fg1	N 27°51'36.3" /E 84°51'25.2"	Uphill side of MDBR about 400m away from Bairenitar	Thin to thick bedded, med.- to coarse-grained, white and pink quartzite	Slightly to moderately
Fg2	N 27°51'30.2"/ E 84°51'0.9"	Uphill side of MDBR, 50 m toward NE direction from Dam site	Medium to thick bedded, coarse-grained, yellow to pink orthoquartzite with wave ripples	Moderately
Da1	N 27°50'55.9"/ E 84°50'52.8"	Uphill side of MDBR , about 50 m downstream from canal dam to Malekhu	Thinly foliated, dark grey, graphitic phyllite interbedded with metasandstone.	Slightly to moderately
Np1	N 27°49'44.2" /E 84°50'42.5"	Right uphill side of MDBR about 500 m away from Katledada	thin to thick bedded, coarse-grained, white siliceous dolomite with phyllite partings.	Slightly
Np2	N 27°50'3.9"/ E 84°50'51.7"	Uphillside of MDBR, 30 m toward the Malekhu from the Mawi Khola	Dark grey finely crystalline quartzite with thinly foliated greenish grey phyllite.	Moderately
Np3	N 27°50'33.3" /E 84°50'44.4"	Left bank of the Thopal Khola near the Bungchung Bridge	Coarse-grained , yellowish grey quartzite intercalated with greenish grey phyllite	Slightly
Dh1	N 27°49'38.6" /E 84°50'44.5"	Uphillside of the MDBR towards the Dhading Besi	Light grey, thinly laminated, planar dolomite.	Moderately
Bg1	N 27°49'20.2"/ E 84°50'42.8"	Uphillside of MDBR towards the Dhading Besi	Intercalation of planar, thinly laminated grey calcareous slate.	Moderately
Bg2	N 27°48'44.1" /'E 84°50'12.7"	Right bank of the Trisuli River, near the Suspension Bridge	Dark grey, fine grained, calcareous, laminated slate with some quartz lenses.	Moderately
Ml1	N 27°48'30.3" / E 84°50'2.1"	Left bank of the Malekhu Khola (MK), about 100 m upstream from Malekhu Bridge	Laminated, planar, finely crystalline dark grey dolomite.	Slightly
Ml2	N 27°48'19.2"/ E 84° 49' 58"	Right bank of the Malekhu River, about 50 m upstream from the Malekhu Bridge	Finely crystalline, planar, dark grey dolomite.	Slightly
Rb1	N 27°47'55.8" /E 84°50'13.1"	Left bank of the MK, about 250 m downstream from the confluence with the Dhobi Khola	Medium to coarsely crystalline, foliated, planar, dark grey to white, psammatic schist.	Slightly
Rb2	N 27°47'39.6" /E 84°50'27.9"	Left bank of the MK, about 375m downstream from the confluence with the Dhobi Khola	Grey quartzite intercalated with greenish grey schist with quartz veins.	Moderately
Rb3	N 27°48'11.3"/ E 84°50'3.1"	Left bank of the MK, about 750 m upstream from the Malekhu Bridge	White sericitic quartzite with thin sericitic parting with chlorite schist.	Slightly
Rd1	N 27°47'51.9" /E 84°50'8.4"	Right bank of the MK, near the confluence of the MK and Dhobi Khola	Greenish grey, biotite present garnetiferous schist.	Slightly
Rd2	N 27°47'42.2" /E 84°49'57.1"	Left bank of the MK about 700 m away from the Amiltar.	Greenish grey, medium grained garnetiferous schist with frequent quartz lenses.	Slightly
Bd1	N 27°47'33.7"/E 84°49'49.2"	Left bank of the MK, scarp slope.	Coarsely crystalline,wavy, white colored marble	Slightly to moderately
Ka1	N 27°47'33.9"/ E 84°49'41.6"	Left bank of the MKr about 600 m away from the Bhuttar.	Intercalation of micaceous schist with fine crystalline dark grey medium grained quartzite.	Slightly to moderately
Ch1	N 27°46'50.8" /E 84°49'49.5"	Right bank of the MK 750 m away from Chhepan.	Light grey, planar, quartzite with thin parting of schist.	Slightly
Kh1	N 27°46'43.7" /E 84°49'52.9"	Right bank of MK about 650 m away from Cheppan.	Dark grey biotite schist with few bands of migmatites.	Slightly to moderately
Kh2	N 27°46'45.2" /E 84°49'50.9"	Right bank of MK about 600 m away from Chhepan.	Massive augen gneiss.	Slightly
Kh3	N 27°46'8.1"/E 84°49'19.3 "	Left bank of MK, about 20 m away from Chhepan	Dark grey medium grained biotite schist intercalated with some light grey quartzite.	Slightly
Ti1	N 27°45'26.3" /E 84°49'21.4"	Right bank of the MK about 50 m downstream from the confluence with the stream	Dark grey, planar, thinly laminated, biotite rich metasiltstone.	Slightly

Index Properties

Toughness of rock was accessed via porosity, dry density, specific gravity and point load index test in the laboratory. Aggregate specific gravity is useful in making weight-volume conversions and in calculating the void content in compacted HMA (Roberts et al. 1996). ASTM E1547-09 (2009) defined specific gravity. Specific gravity (saturated surface-dry basis) was calculated by using the given relation.

Porosity, a ratio of volume of the voids to the total volume, describes how densely the material is packed. Porosity of the rock samples was calculated by using the following relation:

$$\text{Porosity} = ((B-A)/(\text{Volume of samples}))100 \qquad (6)$$

Where, B = Saturated surface-dry weight (g), A = Oven-dry weight (g)

Dry density was calculated using the following relation:

$$\text{Dry Density}=(A/(\text{Volume of samples}))100 \qquad (7)$$

Where, A = Oven-dry weight, in grams (g). Specific gravity (saturated surface-dry basis) was calculated by using the given relation:

$$\text{Specific Gravity}= B/(B-C) \qquad (8)$$

Where, B = saturated surface-dry weight, in grams C = weight of saturated sample immersed in water, in grams

Point load strength test is intended as an index test for the strength classification of rock material. It obtains an indirect measure of the compressive strength of rock cores and can also be used on lump rock. A load is diametrically applied through conical platens, the ram being driven by a hand-operated hydraulic pump. A gauge measures the load at failure, giving a measure of the tensile rock strength.

Point load strength (I_s) was calculated as per the following relations.

$$I_s = P/De^2 \qquad (9)$$

Where, P = Failure Load, De^2 = Equivalent core diameter for an irregular rock lump (mm)

$$De^2 = 4A/\pi \qquad (10)$$

A= Minimum cross-sectional area of plane through the platen contacts point and

$$A=WD \qquad (11)$$

$$W = (W_1+W_2)/2 \qquad (12)$$

Where, W_1 = upper surface width of rock specimen, W_2= lower surface width of rock specimen.

$$F = (De/50)^{0.45} \qquad (13)$$

Where, F= Size correction factor.

Finally,

$$I_{s(50)} = F\times I_s \qquad (14)$$

where, I_s = Point load strength index, MPa

RESULTS

The composition of the analysed rock types (all together 26 samples) from the study area is tabulated (Table 3). Rock types identified are two slates, three phyllites, seven schists, one augen gneiss, six quartzite, one amphibolites, one marble, four dolomites and one metasiltstone. Textural study of the samples of different rock types were done through grain size homogeneity, index of interlocking and texture coefficient, and the results are given in Table 4.

Micropetrographic Index (K)

Micropetrographic index (K) ranges from 0.05 to 49 and it is highest in the quartzite of the Nourpul Formation ‘Np3’ due to presence of more than 98 % quartz and lowest in the dolomite of the Dhading Dolomite ‘Dh1’ since dolomites are highly prone to chemical weathering as dolomite will dissolve with most forms of acid like carbonic acid. Siliceous rock have higher micropetrographic quality index than schists, phyllites and dolomites because of presence of high percentage of quartz. Among siliceous rock, ‘K’ value is less in the quartzites of the Robang Formation ‘Rb1’ and the Chisapani Quartzite ‘Ch1’ due to increased mica content. Carbonate rocks have the lowest micropetrographic quality index since the carbonate minerals such as limestone, dolomite and calcite are highly prone to chemically weathering. Thus they are considered as unsound constituents making low

Table 3: Mineralogical Composition of the rock samples from the Malekhu-Thopal Khola area

Samples	Rock type	Mineral Composition, %													
		Q	P	K	Cal	Dol	Mus, Ser	Bio	Chl	Grn	Hnb	Opaque/ Fe	Trm	C	Total
Kn1	Mylonitic Schist	67					30		3						100
Kn2	Phyllite	45					53					2			100
Fg1	Quartzite	95					5								100
Fg2	Quartzite	95					3					1	1		100
Da1	Phyllite	20					77					3			100
Np1	Silicious Dolomite	30			65		5								100
Np2	Phyllite	60					38					1	1		100
Np3	Quartzite	98										2			100
Dh1	Dolomite	5				94	1								100
Bg1	Slate	20				35	20					1		24	100
Bg2	Slate	35					15		30					20	100
Ml1	Dolomite	15			10	68	7								100
Ml2	Dolomite	10			15	65	10								100
Rb1	Psammitic Schist	70		13			15					1	1		100
Rb2	Quartzite	91					8					1			100
Rb3	Quartzite	94					7					1			102
Rb4	Amphibolite	9	40								50	1			100
Rd1	Schist	50			2		48								100
Rd2	Schist	73					26					1			100
Bd1	Marble	7			85			8							100
Ka1	GarnetiferousSchist	75						21		3		1			100
Ch1	Quartzite	88					10					1	1		100
Kh1	Biotite Schist	64		5			20	10					1		100
Kh2	Augen Gneiss	42	8	40			10								100
Kh3	Biotite Schist	65		10			10	13				2			100
Ti1	Metasiltstone	60					38					2			100

Q = quartz; P = Plagioclase; K = K-feldspar; Cal = calcite; Dol = dolomite; Mus, Ser = muscovite, sericite; Bio=biotite; Chl = chlorite; Grn = garnet; Hnb = hornblende; Trm; C = carbonaceous grain

'K' value. But they are mechanically sound. Foliated rocks like slate, phyllite and schist also have low micropetrographic quality index because of greater mica content but psammatic schist of the Robang Formation 'Rb1' has more 'K' value in comparison to other foliated rocks due to high percentage of quartz composition. The amphibolite of the Robang Formation 'Rb4' has also low 'K' value because of high amount of hornblende present in it. Hornblende alters easily to chlorite. Hence it is considered as unsound mineral.

Index of Interlocking

Index of interlocking express the grain to grain relationship. Larger the number of contacts between grain-to- grain, the greater the interlocking among framework grains in the rock (Kahn, 1956). Packing proximity, similar to interlocking is the most influencing petrographic characteristics (Zorlu et. al., 2004).

Interlocking has positive correlation with

Table 4: Calculated values of texture coefficient, grain size homogeneity, micropetrography quality index and shape factor

Rock Type	Samples	K	g %	t	SF	TC
Phyllite	Kn2	1.86	22	0.74	0.71	1.42
	Da1	0.56	10	0.22	0.72	1.45
	Np2	3.55	11	0.16	0.7	1.42
Slate	Bg1	0.27	46	0.23	0.74	1.24
	Bg2	0.22	7	0.31	0.69	1.19
Schist	Kn1	3.55	24	0.09	0.68	1.43
	Rb1	6.14	55	0.14	0.71	1.21
	Rd1	0.69	21	0.15	0.63	1.71
	Rd2	2.23	23	0.16	0.69	1.08
	Ka1	3.00	36	0.16	0.61	1.34
	Kh1	3.00	41	0.18	0.59	1.28
	Kh3	2.70	52	0.21	0.72	1.51
Quartzite	Fg1	32.33	43	0.06	0.72	1.35
	Fg2	24.00	31	0.06	0.68	1.92
	Np3	49.00	87	0.29	0.7	1.44
	Rb2	10.11	58	0.11	0.7	1.42
	Rb3	19.00	69	0.1	0.74	1.23
	Ch1	7.33	28	0.15	0.55	1.48
Augen Gneiss	Kh2	5.67	48	0.14	0.57	1.97
Marble	Bd1	0.10	92	0.51	0.73	1.27
Amphibolite	Rb4	8.09	65	0.1	0.65	1.66
Dolomite	Np1	0.59	85	0.19	0.73	1.37
	Dh1	0.05	88	0.23	0.8	1.27
	Ml1	0.27	79	0.18	0.7	1.42
	Ml2	0.19	72	0.13	0.6	1.33
Metasiltstone	Ti1	0.79	14	0.17	0.81	1.24

micropetrographic index (Fig. 3). Marble of the Bhainsedobhan Marble Bd1 has the highest interlocking i.e 92% while slate of the Benighat Slate has the lowest 7% interlocking. Carbonate rocks also have very good interlocking. Similarly, quartzites of ‘Np3’, ‘Rb2’ and ‘Rb3’ and psammatic schist ‘Rb1’ also have good interlocking. Quartzite of the Nourpul Formation ‘Np3’ has the greatest index of interlocking while quartzite of the Chisapani Formation has the lowest interlocking among the siliceous rocks. Interlocking of quartzites from the Chisapani Quartzite ‘Ch1’, and the Robang Formation ‘Rb2’ and ‘Rb3’ are affected by mica content. The poorer interlocking in the quartzites of the Fagfog Quartzite is due to presence of small grains. Texturally all these quartzites differ from one another (Fig. 4). The quartz grains smaller than 40 μm are considered as matrix. Matrix to grain contact does not contribute to increase interlocking. Index of interlocking is very good in carbonate rocks. The Bhainsedobhan Marble ‘Bd1’ has the highest interlocking of all because it has very well developed coarse grains and there is excellent grain to grain contact. Carbonates rocks like limestone and dolomite are finely crystalline and calcite and dolomite minerals present in them precipitates filling all the voids which increase the interlocking. There is poor interlocking in foliated rocks. Among the foliated rocks, schists are more interlocked than phyllites and slates. The Benighat Slate ‘Bg2’ has the lowest index of interlocking of all rock types. The main reasons for poor interlocking in foliated rocks are small grain size and dominantly presence of micas.

Grain Size Homogeneity (t)

Index of grain size homogeneity (t) is introduced by Dreyer (1973). Its value increases when there is dominance of one grain size group but decreases rapidly as soon as big or small grains occur in the matrix. The textural homogeneity is maximum in the phyllite of the Kuncha Formation Kn2 and minimum in the quartzites of the Fagfog Quartzite Fg1 and ‘Fg2’. Hence ‘Kn2’ has very well sorted grains while ‘Fg1’ and ‘Fg2’ have very poorly sorted. ‘Bd1’ of the Bhaisedobhan Marble also

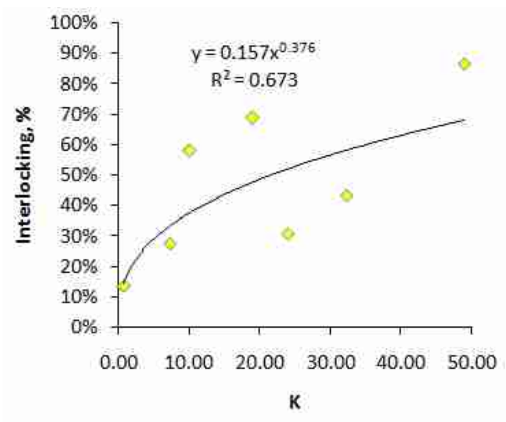

Fig. 3 Interlocking vs. micropetrographic index

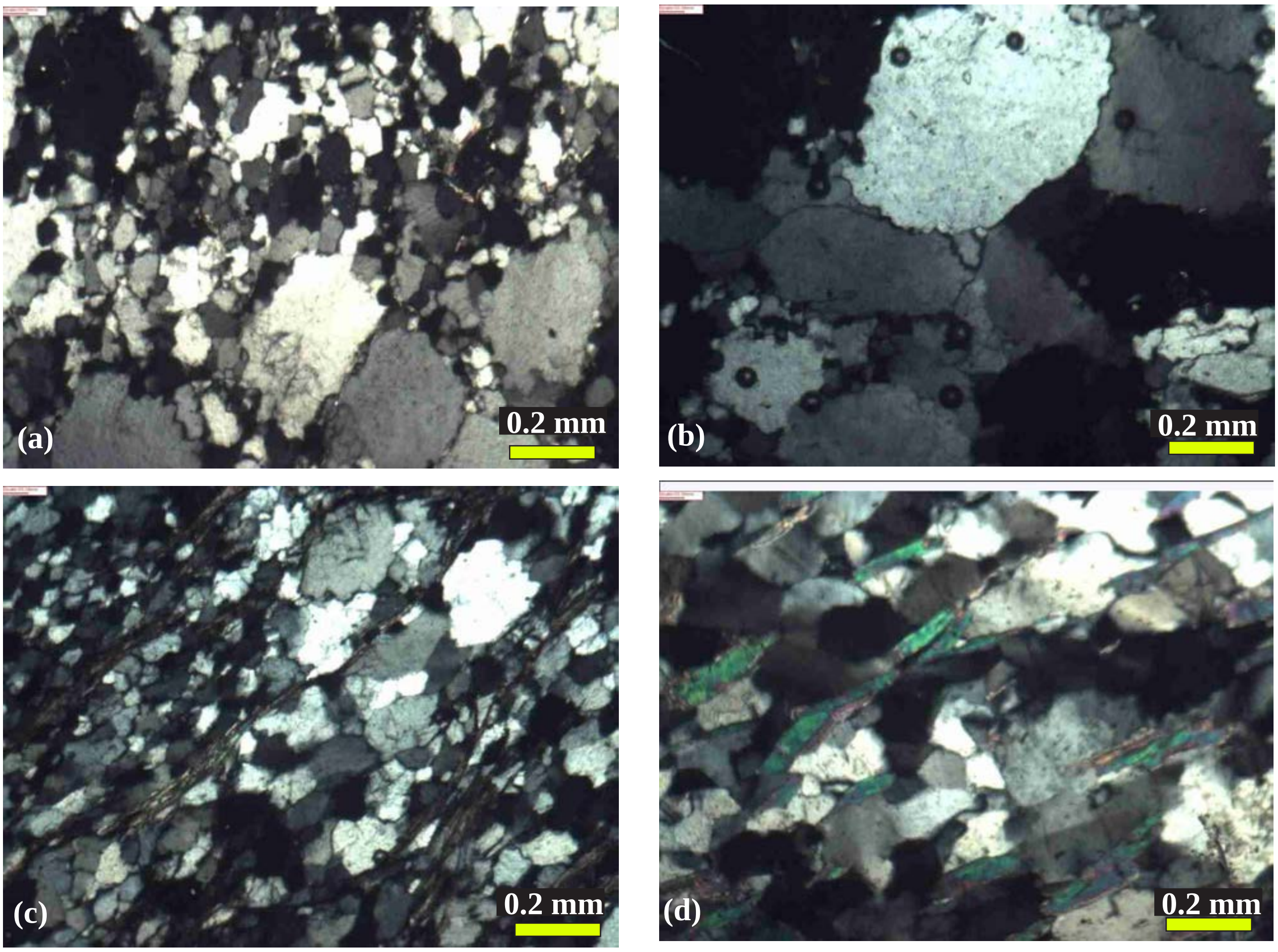

Fig. 4 Quartzites from the study area: (a) Quartzite 'Fg1' showing granular texture and without foliation, (b) Quartzite 'Np3' showing granular texture without foliation, (c) Quartzite 'Rb2' showing poorly developed foliation with domains of cleavage and microlithon, and (d) Quartzite 'Ch1' showing well developed foliation with distinct domains of microlithons and cleavages.

has good sorting. 'Dh1', 'Bg1', 'Bg2', 'Da1', 'Kh3' and 'Np3' are moderately sorted and their value ranges from 0.21-0.31. Grain size homogeneity is decreased in poorly sorted rocks that are in the rocks which possess wide ranges of grain size. If there is presence of porphyroblasts it decreases rapidly. More the number of grains we consider, there decrease more in grain size homogeneity because summation of A_i-A_{avg} will be increased which decrease the value of grain size homogeneity. 'Kn2' has the highest grain size homogeneity since it is composed of dominantly equal size of fine grains. Fg1 and Fg2 have the lowest grain size homogeneity because they consist of wide range of grains ranging from 40 µm to 1 mm. Mylonitic schist of the Kuncha Formation 'Kn1' has also the lowest grain size homogeneity because it has fine grain matrix along with big grain up to 1.2 mm. Grains are poorly sorted in Kn1 with granoblastic texture. Siliceous rocks have low grain size homogeneity but quartzite of the Nourpul Formation has good grain size homogeneity. It consists of well sorted grains of 400-500 µm size. Carbonate rocks also have low grain size homogeneity except marble of the Bhaisedobhan Marble due to presence of coarse grains of calcite of homogeneous size. Foliated rocks also have low value except in 'Kn1'.

Texture Coefficient (TC)

Howarth and Rowlands, 1986 developed the theory of texture coefficient (TC), which made it possible to understand the variations of mechanical properties of rocks with rock textural properties. Texture Coefficient considers grain packing weighting (AW), shape factor

(SF_0), aspect ratio (AR) and angle factors (AF1) which means interlocking, grain shape and orientation is considered.

Shape Factor (SF_0) is a parameter of the grain's deviation from circularity. If SF_0 is equal to 1.0, it means that the particle is a perfect sphere. Shape factor ranges from 0.55-0.81 and grain of Tistung Formation 'Ti1' has the highest SF_0 0.81 while the Chisapani Quartzite 'Ch1' has the lowest 0.51 (Table 4).

Texture coefficient ranges from 1.08-1.97. It is maximum in the augen gneiss of the Kulekhani Formation 'Kh2' while minimum (1.08) in the schist of the Raduwa Formation 'Rd2'. 'Kh2' has the greatest TC due to presence of angular and elongated grains that are randomly oriented that means due to high aspect ratio and low shape factor and high angle factor. 'Rd2' has the lowest TC because grains are quite elongated but short and have preferred orientation that means high shape factor value and low angle factor. TC is high in schists of the Raduwa Formation 'Rd1' and amphibolite of the Robang Formation Rb4 because of high angle factor and aspect ratio. In the siliceous rock TC is around 1.4 and grains are less preferred oriented and slightly elongated. TC in foliated rocks is generally affected by high aspect ratio. Carbonate rocks have low TC around 1.3 which is due to high shape factor value.

Index properties

Specific gravity of all the rock is found to be in between the range of 2.08 (Bg2) to 3.08 (Kn2) (Table 5). Specific gravity of 2.65 is better for roadstone and 2.5 for filter aggregate.

The dry density of Bg2 is the lowest i.e. 2309 kg/m^3 and highest is of Kn2 i.e. 3224 kg/m^3 (Table 5). Dry density determined for quartzite in this study shows positive correlation with grain size homogeneity (Fig. 5). Dry density of aggregates used in construction is 2000-3000 kg/m^3 and average value is about 2600 kg/m^3 used in road construction (AASHTO, 1993). The result shows that samples have low effective porosity. Most of the rock aggregates falls into the normal density category of aggregates. The density ranging between 2000 and 3000 kg/m^3 can also be considered medium weight aggregate, and the samples which have dry density exceeding 2600 kg/m^3 are more suitable for aggregate (Zafir and Majid, 2000). Dry density of 2600 kg/m^3 is considered average for road construction (AASHTO, 1993).

Porosity is less than 2% of all the rocks except the slates of the Benighat Slate and augen gneiss (Kh2) of the Kulekhani Formation. This shows that rocks have low effective porosity. Porosity of rocks correlates positively with micropetrographic index of highly foliated rocks (slate, phyllite and schist) (Fig. 6). Porosity of rocks is decreasing with increasing metamorphic grade. Grains of augen gneiss were rounded and approximately one size which increased the porosity of augen gneiss. The rock having low effective porosity is strong enough to withstand chemical decomposition against cement and weathering fluid. Porosity of calcareous slate Bg2 (8.91%) is greatest among all the samples whereas smallest is 0.04% of Kh1 (Table 5). The result shows that porosity of low grade metamorphic rocks is comparatively more than that of other quartzite, schist and gneiss. As the porosity of Bg2 (8.91%) is greatest among all the samples, its WAV is also greatest (4.75%). Similarly, porosity of Kh1 (0.08%) is smallest as a result WAV is also the smallest (0.04%). Water absorption value of most of the rock is found less than 1%. It means most of the rock of the area is less porous. The absorption value greater than 3% is not recommended for concrete aggregate and road construction (ASTM, C 127). So the rocks of location Bg1 and Bg2 are not suggested to use in concrete aggregate. Result shows that WAV of low grade metamorphic rocks are comparatively greater than that of high grade metamorphic rocks.

The result of point load strength index (Table 6) is lowest of the slate of the Benighat Slate (Bg2) which was calculated to be 0.26 MPa. Similarly, the highest value of point load index is that of psammatic schist of the Robang Formation (Rb1) which was calculated to be 301.9 MPa (Table 6). Based on strength classification after conversion of point load strength index to uniaxial compressive stregth (UCS) after Bieniawski (1975), most of the samples fall in to the range from very low to high strength rocks (Table 7). The point load strength index correlates moderately with micropetrographic index of foliated rocks (Fig. 7). Greater the micropetrographic indices in rocks the higher the point-load strength index. Besides, it is also influenced by degree of foliation and constituent minerals in rocks.

Table 5: Index properties values of the samples from the study area

Sample	Oven dry weight (gm), A	Saturated surface dry weight (gm), B	Wt. of saturated sample immersed in water (gm), C	Vol. of the sample immersed in water (gm), C	Specific gravity	Dry Density (kg/m)	Porosity (%)	Water Absorption Value (%)
Kn1	472.23	474.78	299.44	172.79	2.69	2733	0.94	0.53
Kn2	343.32	348.22	236.82	106.5	3.08	3224	1.59	1.42
Fg1	482.55	484.11	305.94	176.61	2.7	2732	0.57	0.32
Fg2	248.21	250.46	154.23	93.98	2.57	2641	0.87	0.9
Da1	454.32	455.57	286.53	167.79	2.68	2708	0.46	0.27
Np1	392.14	394.02	253.48	138.66	2.79	2828	0.67	0.47
Np2	360.28	362.59	228.65	131.63	2.68	2737	0.85	0.64
Np3	215.63	216.85	140.16	75.47	2.81	2857	0.43	0.56
Dh1	420.21	423.85	271.08	149.13	2.75	2818	1.32	0.86
Bg1	402.36	421.41	240.78	161.58	2.22	2490	8.55	4.73
Bg2	390.13	408.68	221.15	168.98	2.08	2309	8.91	4.75
Ml1	399.23	401.63	256.51	142.72	2.75	2797	0.87	0.6
Ml2	438.31	438.85	283.33	154.98	2.81	2828	0.19	0.12
Rb1	206.11	207.21	127.92	78.19	2.59	2636	0.42	0.53
Rb2	425.32	425.97	266.46	158.86	2.66	2677	0.24	0.15
Rb3	407.31	408.35	253.07	154.24	2.62	2641	0.39	0.25
Rd1	497.33	499.51	317.28	180.05	2.72	2762	0.79	0.43
Rd2	370.36	371.01	234.01	136.35	2.7	2716	0.24	0.17
Bd1	404.88	405.92	268.64	136.24	2.95	2972	0.76	0.26
Ka1	451.31	455.2	286.46	164.85	2.67	2738	1.45	0.86
Ch1	382.23	383.1	238.82	143.41	2.65	2665	0.32	0.22
Kh1	485.69	485.91	303.73	181.96	2.66	2669	0.08	0.04
Kh2	444.23	450.22	275.48	168.75	2.54	2632	2.35	1.34
Kh3	354.31	356.88	221.81	132.5	2.62	2674	0.97	0.72
Ti1	301.55	303.84	191.05	110.5	2.67	2729	0.85	0.75

CONCLUSIONS

Micropetrographic quality index ranges from 0.05-49 and is highest in quartzite of the Nourpul formation 'Np3' and lowest in the dolomite of the Dhading Dolomite 'Dh1'. The rocks with high density, low porosity, and greater strength show higher micropetrogaphic quality index. Micropetrographic index has great influence on porosity and point load strength index of the highly foliated rocks like slate, phyllite and schist. Therefore it is an important parameter.

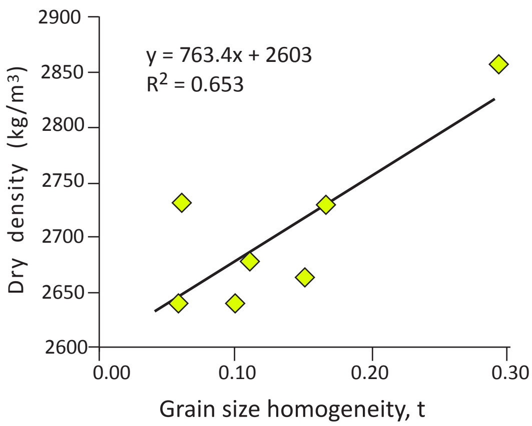

Fig. 5 Dry density vs. grain size homogeneity

Table 6: Results of determination of point load strength index

Sample	W (mm)	D (mm)	A (mm^2)	De² (mm^2)	P (KN)	I_s (KPa)	De (mm)	F	$I_{s(50)}$	[1] UCS	*Strength classification
Kn1	51	56	2856	3636	10.5	2887	60.3	1.09	3.14	72.3	Medium
Kn2	52.5	41	2153	2741	1.75	639	52.35	1.02	0.65	15	Very low
Fg1	55	57	3135	3992	19.75	4948	63.18	1.11	5.5	126.4	High
Fg2	39	38	1482	1887	13.0	6889	43.44	0.94	6.47	148.7	High
Da1	56.5	45	2543	3237	21.0	6487	56.9	1.06	6.88	158.1	High
Np1	53	50	2650	3374	14.75	4371	58.09	1.07	4.68	107.5	High
Np2	50	49	2450	3119	8.80	2821	55.85	1.05	2.97	68.2	Medium
Np3	51	30	1530	1948	4.50	7250	44.14	0.95	6.89	158.4	High
Dh1	40	55	2200	2801	2.75	982	52.93	1.03	1.01	23.2	Very low
Bg1	47	53	2491	3172	6.25	1971	56.32	1.05	2.08	47.8	Low
Bg2	56.5	62	3503	4460	1.00	224	66.78	1.14	0.26	5.9	Very low
Ml1	50	50	2500	3183	18.75	5890	56.42	1.06	6.22	143	High
Ml2	49	52	2548	3244	4.75	1464	56.96	1.06	1.55	35.7	Low
Rb1	46	32	1472	1874	26.25	14006	43.29	0.94	13.13	301.9	Very high
Rb2	49.5	50	2475	3151	3.75	1190	56.14	1.05	1.25	28.8	Low
Rb3	55.5	43	2387	3039	7.00	2304	55.12	1.04	2.41	55.4	Medium
Rd1	55	56	3080	3922	9.00	2295	62.62	1.11	2.54	58.4	Medium
Rd2	50	42	2100	2674	12.75	4768	51.71	1.02	4.84	111.3	High
Bd1	25	64	1600	2037	4.25	2086	45.14	0.95	1.99	45.8	Low
Ka1	52.5	40	2100	2674	17.5	6545	51.71	1.02	6.64	152.8	High
Ch1	48	51	2448	3117	19.25	6176	55.83	1.05	6.49	149.3	High
Kh1	58.5	43	2516	3203	14.25	4449	56.59	1.06	4.7	108.2	High
Kh2	62.5	45	2813	3581	2.75	768	59.84	1.08	0.83	19.2	Very low
Kh3	49.5	48	2376	3025	14.1	4661	55	1.04	4.87	111.9	High
Ti1	39	54	2106	2681	3.50	1305	51.78	1.02	1.33	30.5	Low

[1] UCS Empirically calculated; *after Bieniawski (1975)

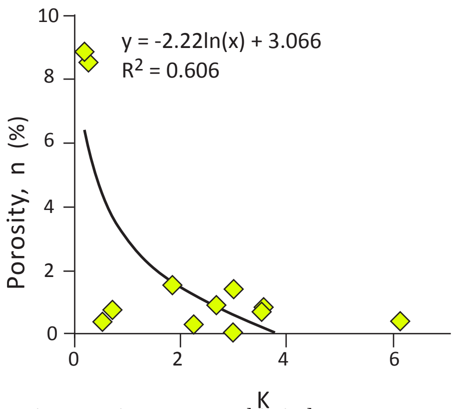

Fig. 6 Porosity vs. micropetrographic index

Table 7: Intact rock classification

UCS (MPa)	Strength Class	Sample number
>200	Very high	Rb1
100-200	High	Fg1, Fg2, Da1, Ml1, Rd2, Ka1, Ch1, Kh1, Kh3, Np1, Np3
50-100	Medium	Kn1, Np2, Rb3, Rd1
25-50	Low	Bg1, Ml2, Rb2, Bh1, Ti1
<25	Very low	Kn2, Dh1, Bg2, Kh2

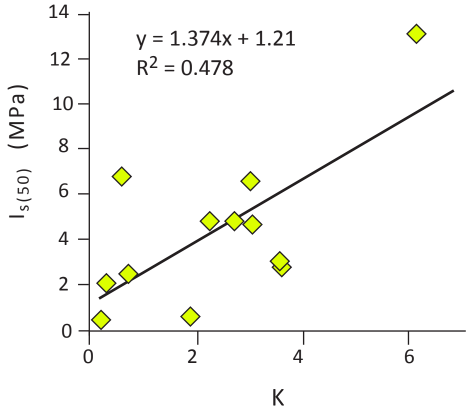

Fig. 7 Point load strength index vs. micropetrographic index

Siliceous rocks having high texture coefficient is mechanically sound. When homogeneity in grain size, shape and orientation increases, texture coefficient diminishes. Therefore, texture coefficient is important variable.

WAV of the samples is below 2% except the slates (Bg1 and Bg2) of the Benighat Slates which indicate that most of the rocks have low effective porosity.

The rock samples classified range from very low to very high strength rock categories. Out of twenty six samples four fall into very low, five into low, four into medium, eleven into high and one into very high classes.

Based on data of composition, texture and index properties, the rock types recommended for the construction aggregates are quartzites of the Nourpul Formation, the Fagfog Quartzite, and the Chisapani Quartzite, and psammitic schist of the Robang Formation. The quartzites samples from the Fagfog and the Norpul Formations may also be useful for silica sources. Siliceous dolomite of the Nourpul Formation ‘Np3’ and dolomite of Malekhu Limestone ‘Ml1’ are regarded as the good material as they possess high interlocking, high strength and high density.

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