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Evaluation of strength and durability of rocks from Malekhu-Thopal Khola area, Central Nepal Lesser Himalaya for construction aggregates

* Krishna Bista and Naresh Kazi Tamrakar

Central Department of Geology, Tribhuvan University, Kathmandu, Nepal

ABSTRACT

Aggregate, the inert materials used in almost every field of modern development structures have great influence. Aggregates may look similar in appearance but they may carry different physical, mechanical and chemical properties and they may perform accordingly. End uses of aggregates are also determined by their performance. The Lesser Himalaya of the Malekhu-Thopal area comprises more than 14 formations having great potential of rock aggregates. The present study was carried out in order to reveal the toughness and soundness of each rock type of the Lesser Himalaya so that durability can be determined. Altogether 25 representative samples were tested to find porosity, specific gravity, dry density, uniaxial compressive strength (UCS), Los Angeles abrasion value (LAAV), aggregates impact value (AIV), sodium sulphate soundness Value (SSSV), ethylene glycol soaking value and water absorption value (WAV). Results were compared with standards of different specifications and recommended for wide range end uses.

Rock mass rating of each formation was carried out and the value ranges from 36 to 82. Specific gravity ranges from 2.08 to 3.08 and the dry density ranges from 2.3 to 3.22 g/cm^3. All the samples have porosity less than 2% except the samples of the Benighat Slate. UCS value ranges from 5.9 to 301.9 MPa. The LAAV of the sample lies between 19.6% and 47.5%. AIV is between 8.54% and 34.28%. The SSSV ranges from 2.35 to 26.06%. Ethylene glycol soak index is 2 of all samples signifying that proportion of swelling clays or low accessibility of ethylene glycol through the samples due to low porosity. WAV of all the samples is below 2% except the Benighat Slates which indicates that the aggregates have low effective porosity. The entire test shows that most of the sample meets different national and international standards and can be recommended for wide range of end uses.

Key words: Aggregates, durability, index properties, strength, Los Angeles abrasion, rock mass rating

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INTRODUCTION

Development structures are the infrastructures of the nation. The infrastructures of the development should be strong enough to resist the load, and durable enough to run for several decades. More than 90% of asphalt pavement and 80% of concrete consist of construction aggregate. Crushed stones and sand and gravel share subequal proportion to the construction aggregate source. A typical pavement layer requires about 2000 cubic meter of selected material per kilometer (Paige-Green, 2004). The key properties of aggregate such as petrographical and physical properties have a bearing effect on engineering application (Přikryl, 2001; Akesson et al., 2001; Al-Harthi, 2001; Azimah and Colin, 2010). Poor aggregates in terms of durability may have disastrous consequences. Therefore, its quality is of significant importance. The Malekhu-Thopal Khola area possesses more than fifteen geological formations and has got great potential of rock aggregates. Several quarry sites are running on the banks of these rivers. Therefore, the durability of rock

*Corresponding author:

E-mail address: amateurbista05@yahoo.com

aggregates of each formation is important to be studied well before using them in various development structures but not any kind of such studies has been done yet.

Smith and Collis (1993) identified main factors influencing aggregate behavior in various operational and environmental conditions, and relevant standards and other specifications and code of practice. They concluded that the performance of aggregates depends upon their intrinsic properties. Physical and mechanical properties of the Lesser Himalayan rocks and the Sub-Himalayan rocks were studied by several workers (Tamrakar et al., 2002; Maharjan and Tamrakar, 2003; Dhakal et al., 2006; Khanal and Tamrakar, 2009; Paudel, 2012). Tamrakar et al. (2002) determined dry density and porosity of Siwalik sandstones from the Central Nepal and concluded that these properties were related well with uniaxial compressive strength, point load index and modulus ratio. Dhakal et al. (2006) studied freeze–thaw experiments on the limestones and sandstones from Japan, and dolomite and schist from Nepal and concluded that initiation and extension of cracks and subsequent wearing and deterioration occurred relatively faster in the rock having a high porosity. The durability of freeze–thaw was also greatly influence by mineralogy.

Maharjan and Tamrakar (2007) determined dry density of samples from the Rapti Rivers between 2460 and 2680 kg/m^3, aggregate impact values between 14.2% and 16.1%, and magnesium sulphate soundness values between 4.46% and 7.29% suggesting good resistance against chemical weathering and frosting, good soundness, durability and workability of those gravels for road and concrete aggregates.

Analysis of physical, mechanical and petrographical properties of sandstones from the Siwalik Group was made by Tamrakar et al. (2007) and concluded that the strength of the sandstone depends upon the % void, strong over weak contacts, strong cement over total cement, packing density and concavo-convex contacts among grains. Quality of crushed limestone and siltstone for road aggregates from Adeshwar area Sitapaila, Kathmandu was studied by Khanal and Tamrakar (2009). They analysed rock mass condition of the outcrop and physical, mechanical, chemical and petrographical properties of three distinct varieties of rocks as crystalline limestone, siliceous limestone and calcareous siltstone. They concluded that the aggregates performed better for unbound pavement in roads. Maharjan and Tamrakar (2003) studied and concluded that the metasiltstones from the Tistung Formation, Nallu Khola, Tikabhairav area, Kathmandu Valley, were physically, mechanically and chemically sound and are appropriate for concrete aggregates.

Raghubansi and Tamrakar (2011) studied physical, mechanical and petrographical properties of the Higher Himalayan rocks from the Chaktan Ghasa–Kaligandaki River. They compared the Los Angeles abrasion value of schistose marble with those of augen gneiss and banded gneiss, and concluded that the carbonate minerals could have bonded strongly the other mineral constituents and yielding low Los Angeles abrasion value. They also analysed point load value and concluded that the weak bonding of mineral grains existed perpendicular to foliation plane.

The quality of the aggregates is driven by toughness and soundness which are studied by carrying out physical, mechanical and chemical tests. Durability is the ability of the materials to withstand the effects of environmental conditions, such as water, ageing and temperature variations without any significant deterioration for an extended period (Scholtz and Brown, 1996; Suparma, 2001). Durability i.e. toughness and soundness can be studied by collecting required information along with adequate sample tests. Samples that perform well in all tests are considered as the quality rock aggregates and can be used for several construction purposes. Thus, the main objectives of this study are to determine durability of crushed rock aggregates and evaluate suitability for end-use of these aggregates.

GEOLOCAL SETTING

The Malekhu-Thopal Khola area is located at about 70 km west of the Kathmandu Valley (Fig. 1) and falls within the Dhading District of the Bagmati Zone. The area is linked with the Prithvi Highway, which is considered as a channel linking Kathmandu with Pokhara and other major cities of the country. In this area there are mainly two big rivers: Trishuli Ganga in the east and Buri-Gandaki in the west. The Malekhu, Thopal, Galdu, Charongli and the Tuni Kholas are the major river system of medium sized. The Malekhu Khola flows from SE to NW and the Thopal Khola from NW to SE. Both kholas meet the Trisuli Ganga River.

The study area extends from the Kuncha Formation of the Lower Nawakot Group to the Tistung Formation of the Phulchauki Group of the Kathmandu Complex (Fig. 2). The study comprises 15 formations of the Lesser Himalaya except the Markhu Formation. The Markhu Formation was not well exposed along the Malekhu Khola. The Kathmandu complex is further divided into two groups, viz. the Precambrian Bhimphedi Group consisting of relatively high-grade metamorphic rocks, and the Phulchauki Group of metasedimentary rocks and sedimentary rocks containing fossils of lower-middle Paleozoic age (Stöcklin and Bhattarai, 1977; Stöcklin, 1980). The Phuchauki Group is further subdivided into the Tistung Formation, the Sopyang Formation, the Chandragiri Limestone, the Chitlang Formation, and the Godavari Limestone from the older to the younger sequence. The Bhimphedi Group is also divided into the Raduwa Formation, the Bhaisedobhan Marble, the Kalitar Formation, the Chisapani Quartzite,

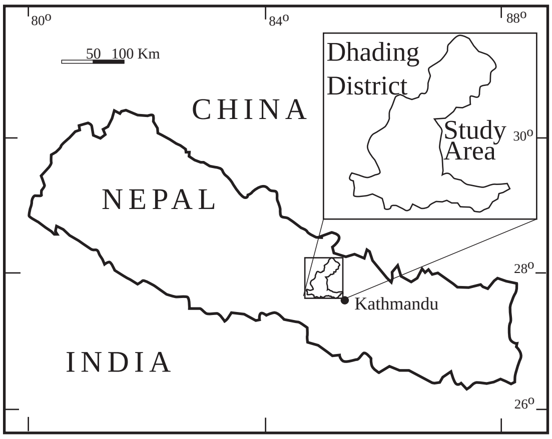

Fig. 1 Location map of the study area

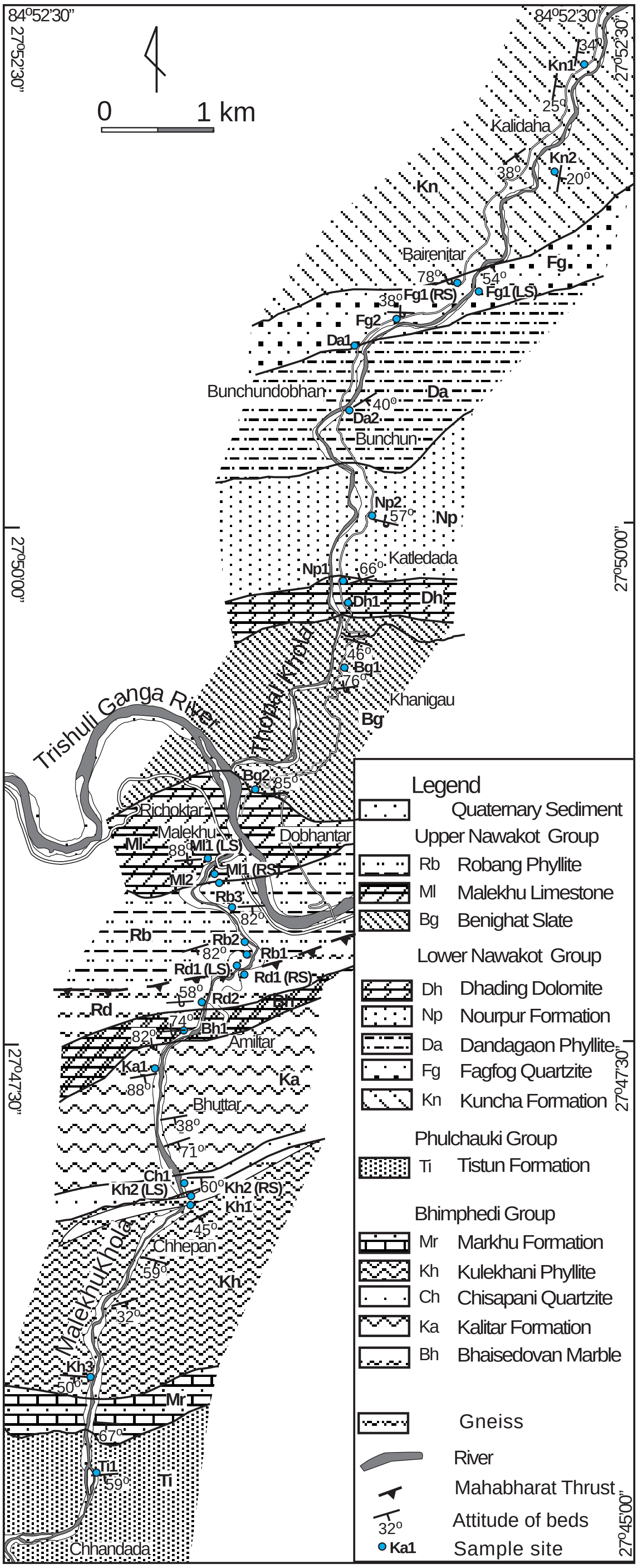

Fig. 2 Geological map of the study area

the Kulekhani Formation, and the Markhu Formation. The low-grade metasedimentary rocks of the Nawakot Complex have been subdivided into the Lower and the Upper Nawakot Groups. Stöcklin and Bhattarai (1977) and Stöcklin (1980) have worked out a detailed stratigraphy of the Nawakot Complex in the surrounding of the Kathmandu Nappe. The Lower Nawakot is further divided into the Kuncha Formation, the Fagfog Quartzite, the Dandagaon Phyllite, the Nourpul Formation, and the Dhading Dolomite from the lower to the upper sequence. The Upper Nawakot Group, comprising of the Benighat Slate, the Malekhu Limestone and the Robang Formation, unconformably overlies the Upper Nawakot. The proposed study area comprises the geological formations of the Lower Nawakot Group and the Benighat Slates of the Upper Nawakot Group across the Thopal River, while the Malekhu Limestone and the Robang Formation of the Upper Nawakot Group, the units of the Bhimphedi Group, and the Tistung Formation of the Phulchauki Group of the Kathmandu Complex across the Malekhu River. The Mahabharat Thrust (MT) separates the Nawakot complex from the Kathmandu Complex (Table 2.1; Fig. 2)

METHODOLOGY

The study was categorized into four: desk study, field study, laboratory works, data processing and interpretation. The desk work consisted of preparatory works. The field work was carried out for geological traverse along Malekhu Khola, Thopal Khola and the Malekhu-Dhading Road section. The Rock Mass Rating was made after Bieniawski (1989). Fresh samples about 4 to 7 kg were collected from each location for the laboratory study and the locations were marked in the topo-sheet.

Several tests were carried out in the different labs according to the availability of the resources. Thin section preparation, petrographic study, water absorption test, dry density test and chemical tests were done in the Central Department of Geology, TU Kirtipur. Aggregate impact test and point load test were conducted in the NEA lab, Swayambu, Kathmandu. Similarly, Los Angeles abrasion test was done in the Rock, Soil and Construction materials testing laboratory of Pulchowk Engineering Campus, Pulchowk Lalitpur.

Table 2.1: 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
	Bhimphe	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

Durability of aggregates

Aggregate is commonly considered inert filler, which accounts for 60 to 80 percent of the volume and 70 to 85 percent of the weight of concrete. Although aggregate is considered inert filler, it is a necessary component that defines the concrete's thermal and elastic properties and dimensional stability (Mehta and Monterio, 1993). Durability of the rock aggregates, which is contributed by toughness and soundness, was accessed via physical, mechanical and chemical tests.

Toughness

Toughness describes how much total energy has to be used before a material breaks. If the material takes a lot of energy (it may change the shape) before breaking, then it is tough material. It can be determined by calculating index properties related to strength. To study index properties 25 representative bulk samples were prepared in the laboratory. Samples cut into cube shape (length 60 mm) were used in determining water absorption, dry density, specific gravity and porosity after ISRM (1979).

Contributions to the weakness of the rock due to the presence of micro cavities should not be overlooked because nearly all rocks, even dense crystalline varieties such as granite, dunite or quartzite, contain micro-cavities (Sprunt and Brace, 1974). Porosity of the rock samples was calculated by using the following relation.

Porosity (n) = (Vv/Vt)100 (%)………(1)

Where, Vv = Volume of the void space (such as fluids) and Vt = Total volume of the sample. Porosity describes how densely the material is packed.

To determine the dry density of the samples the following relation was followed.

Dry density = Wd/Vt…………. (2)

Where, Wd = Dry weight of sample and Vt = Total volume of the sample.

Aggregate specific gravity is useful in making weight-volume conversions and in calculating the void content in compacted HMA (Roberts et al., 1996). AASHTO M132 and ASTM E12 define specific gravity as:" The ratio of the mass of a unit volume of a material at a stated temperature to the mass of the same volume of gas-free distilled water at a stated temperature." The commonly used "stated temperature" is 23°C. Specific gravity is calculated by using the given relation.

Specific gravity, G = W_{SSD}/W_S…………. (3)

Where, W_{SSD} = saturated surface-dry weight, in grams and W_S = weight of saturated sample immersed in water, in grams.

Water absorption is an indirect measure of the permeability of an aggregate which, in turn, can relate to other physical characteristics such as mechanical strength, shrinkage, soundness and to its general durability potential. Water absorption percentage is soundness indicator. Absorption limits are rare in British standards, although BS 8007:1987 does include a recommendation that the aggregate absorption should not 'generally' be greater than 3%. The water absorption value above 4% needs to perform further test on the aggregate to determine its acceptability. The test method of water absorption is accordance to California Test 206 in reference to California test 226, AASTHO T85 and ASTM C127 and 128 (1989). It is determined by measuring the increase in sample weight owing to the pore water expressed as % of dry weight. In this study, the lump sample (almost cube) having a length of 6 cm were immersed in water for 24 hrs and water absorption value relative to dry weight was calculated.

The water absorption value was determined by measuring the increase in sample weight owing to pore water, expressed as percentage of dry weight after ASTM C127 and 128 (1989). Water absorption value was calculated by using the following relation:

WA = B/A.100 (%) …………………. (7)

Where, A = oven-dry weight, in grams, and B = saturated surface-dry weight, in grams

Point load strength test is intended as an index test for the strength classification of rock material. In order to carry out this test, rock specimens in the form of irregular lumps were prepared of each 25 locations. The test procedure was followed after ISRM (2008).

Aggregates undergo substantial wear and tear throughout their life. In general, they should be hard and tough enough to resist crushing, degradation and integration from any associated activities including manufacturing, stockpiling, production, placing and compaction (Roberts et al., 1996). Furthermore, they must be able to adequately transmit loads from the pavement surface to the underlying layers. To determine resistance to abrasion of the samples, Los Angeles abrasion test was carried out. Grade A sample was prepared and the procedure of AASHTO T96-77 (1982) was followed. After preparing samples, they were placed in the Los Angeles abrasion testing machine along with 12 steel balls, the machine was then set to revolve 500 revolutions. After completion of the revolutions the steel balls were taken out first and the samples were placed in a tray. The sample was then sieved at #12 (1.7mm), and the retained sample was weighted. The Los Angeles abrasion value (LAAV) was calculated as abrasion loss in percentage as given below:

LAAV (%) = (W2-W1)/W1.................. (4)

Where, W1 = Initial weight of the sample, and W2= Original weight of sample after test, coarser than 1.70 mm sieve.

Toughness controls resistance to impact. Some sources suggest that the effect of impact is greater than that of abrasion (Smith and Collis, 2001). The aggregate samples passing 12.5 mm sieve and retained on 10 mm sieve of weight about 400 gm were prepared for this test. The aggregates were filled in a cylinder one-third at a time and tamped 25 times with tamping roads. The process was repeated three times. Test samples were then fixed in position on the base of the machine.

The hammer was raised until its lower face was 38 cm above the upper surface of aggregates in the cup, and allowed to fall freely on the aggregate. The test samples were subjected to a total of 15 such blows by the 14 Kg weight of hammer, each being delivered at an interval of not less than one second. The crushed aggregate was then removed from the cup and whole of it was sieved on the 2.36 mm sieve until no further significant amount passes. The mass of an aggregate passing 2.36 mm sieve was taken for calculation of aggregate impact value (AIV).

AIV = (W_2/W_1) 100 (%)..............(5)

Where, W_1 = Total weight of aggregate samples, and W_2 = Weight of an aggregate passing through 2.36 mm sieve.

Soundness

Some types of rock are in fact strong and resistance to weathering, while others breakdown rather easily over time and have molecular structure and mineral more susceptible to weathering and erosion. To evaluate the resistance to weathering, sodium sulphate soundness test, ethylene glycol soak index and water absorption tests were carried out.

The sodium sulphate soundness test was conducted as per the standard procedure of determining the sulphate soundness of aggregates as ASTM Designation C88–05 (ASTM, 2005). The sulphate soundness value (SSV) was calculated as:

After completion of five cycles (Fig. 3) the samples were washed to free it from the salt, oven dried and hand sieved on the same 10 mm sieve. Then sthe sodium sulphate soundness value (SSSV) was calculated using the given equation:

SSV = (W1-W2)/W1.100%   ....(6)

Where, W1 = Initial weight of sample, and W2 = Weight retained on 10mm sieve after five cycle.

Ethylene glycol has been used to access the durability of rocks which contain swelling clay material. This test employs ethylene glycol which causes rapid expansion of swelling clay materials (Paige-Green, 2004). An ethylene glycol index system of Haskins and Bell (1995) was employed.

RESULTS

Rockmass of the study area has been described and their parameters have been given in Table 2 and location of the different sample is shown in Fig. 2.

Rock Mass Rating

Samples from the lower part of the Lower Nawakot Group include mylonite and crenulated phyllite of the Kuncha Formation and quartzite of the Fagfog Quartzite. The rocks are slightly to moderately weathered, thin to thick bedded. Strength of intact rocks

Fig. 3 Samples at different cycles during sodium sulphate soundness test. a) Initial sample before the test, b) Immersion of sample in saturated sodium sulphate, c) Saturated sodium sulphate, d) First cycle, e) Second cycle, f) Third cycle, g) Forth cycle and h) Fifth cycle.

of the area falls between moderately strong to very strong. RQD lies in between fair and excellent. Kn1 and Fg1 have close to moderate spacing of discontinuities whereas Kn2 and Fg2 have close to wide spacing of discontinuities. Three to four sets of prominent joint sets are common in all sample sites. Groundwater condition of Kn1 and Fg2 is completely dry but condition of Kn2 and Fg1 is wet and dry, respectively. With reference to all the parameter of standard RMR classification, RMR value of the area is found between 57 (fair) and 70 (good) (Table 2).

Samples from the upper part of the Lower Nawakot Group include phyllite, quartzite and dolomite of the Dandagoan Phyllite, the Nourpul Formation and Dhading dolomite, respectively. The Dandagoan Phyllite comprises heavily broken, very poor rock mass. Three to four sets of joints are very common in the sample sites. Strength of intact rocks of the samples sites falls between moderately strong to very strong. RQD of Da1 and Dh1 is very poor but Np1, Np2 and Np3 have poor to fair RQD. Spacing of discontinuities is medium to close in all samples except Np3 which has close to wide spacing of discontinuities. Groundwater condition is dry of all sample sites. RMR value of the sample sites ranges from 44 to 64 (Table 2).

Samples from the Upper Nawakot Group include slates of the Benighat Slate, finely crystalline dolomite of the Malekhu Limestone and psammatic schist and quartzite of the Robang Formation. The rockmass condition of sites Bg1 and Bg2 is very poor in

Table 2: Location, lithology and their rock mass rating of the representative samples

Sample	Location	Lithology	RMR
Kn1	On the uphill side (US) of the Malekhu -Dhading road about 1 km away from Kalidanda.	Grn. grey mylonite and thin bedded metasandstone.	57
Kn2	Left bank (LB) of the Sukaura Khola, about 60m upstream from the confluence of it and Thopal Khola.	Thinly laminated greenish gritty phyllite with some quartz veins.	50
Fg1	US of Malekhu Dhading road 400m away from Bairenitar.	Coarse grained pink quartzite with ripple marks.	62
Fg2	US of Dhading road, 50m toward NE from Dam site.	Coarse-grained, yellowish to light grey orthoquartzite.	70
Da1	US of Dhading road, just below the Dam site.	Dark grey, graphitic phyllite and quartzite	44
Np1	Right uphill side (RUS), of Dhading road about 500m away from Katledada.	White, coarsed -grained siliceous dolomite with thin partings of chlorite phyllite.	52
Np2	US of Dhading road, 30m toward Malekhu from Mawi Khola.	Dark grey finely crystalline quartzite with thinly foliated greenish grey phyllite.	49
Np3	LS of Thopal the River about 20m away from the Thopal bridge.	Coarsed-grained , yellowish grey quartzite intercalated with greenish grey chlorite, sericite phyllite .	64
Dh1	On the uphillside of Dhading Highway towards Dhading Besi.	Light grey, thinly laminated, planar dolomite.	52
Bg1	On the uphillside of Dhading Highway towards Dhading Besi.	Intercalation of planar, thinly laminated grey calcareous slate.	38
Bg2	At the right bank of Trisuli River, near the Suspension Bridge.	Dark grey, fine grained, calcareous, laminated slate with some quartz lenses.	36
Ml1	At the left bank of Malekhu Khola, about 100m upstream from Malekhu Bridge.	Laminated, planar, finely crystalline dark grey dolomite.	57
Ml2	At the right bank of Malekhu Khola, about 50m upstream from Malekhu Bridge.	Finely crystalline, planar, dark grey dolomite.	57
Rb1	At the left bank of Malekhu Khola, about 250m downstream from the confluence of Malekhu khola and Dhobi Khola.	Medium to coarsely crystalline, foliated, planar, dark grey to white, psammatic schist.	57
Rb2	LB of the Malekhu Khola, ~ 375m downstream from the confluence of Malekhu khola and Dhobi Khola.	Grey quartzite intercalated with greenish grey schist with quartz veins.	45
Rb3	LB of the Malekhu Khola, about 750m upstream from Malekhu Bridge.	White sericitic quartzite with thin sericitic parting with chlorite schist.	66
Rd1	RB of the Malekhu Khola, at the confluence of the Malekhu Khola and the Dhobi Khola .	Greenish grey, biotite present garnetiferous schist.	60
Rd2	At the left bank of the Malekhu Khola about 700m away from Amiltar.	Greenish grey, medium grained garnetiferous schist with frequent quartz lenses.	50
Bd1	At the left bank of Malekhu River, scarp slope.	Coarsely crystalline,wavy, white colored marble	44
Ka1	At the left bank of Malekhu Khola about 600m away from Bhuttar.	Intercalation of micaceous schist with fine crystalline dark grey medium grained quartzite.	39
Ch1	At the right bank of Malekhu Khola 750m away from Chhepan.	Light grey, planar, quartzite with thin parting of schist.	58
Kh1	RB of the Malekhu Khola about 650m away from Cheppan.	Dark grey biotite schist with few bands of migmatites.	47
Kh2	RB of the Malekhu Khola about 600m away from Chhepan.	Massive augen gneiss.	82
Kh3	LB of the Malekhu Khola, about 20m upstream from Malekhu Bridge.	Dark grey medium grained biotite schist intercalated with some light grey quartzite.	59
Ti1	RB of the Malekhu Khola about 50m downstream from the confluence of Malekhu Khola and stream from Alegau.	Dark grey, planar, thinly laminated, biotite rich metasiltstone.	49

comparison to others sites. RQD of other sampled sites is between poor to good. Spacing of discontinuities is wide to very close. RMR value ranges from 36 (poor) to 66 (good) (Table 2). Due to presence of very jointed rock masses and damp to dripping groundwater condition, the RMR of Bg1 and Bg2 is very low, 38 and 36 respectively. RMR value of Ml1 and Ml2 is equal.

Samples from the lower part of the Bhimphedi Group comprise garnetiferous schist of the Raduwa Formation, coarsely crystalline marble of the Bhaisedobhan Marble, micaceous schist of the Kalitar Formation and quartzite of the Chisapani Quartzite. Strength of intact rocks of all the sampled sites is strong except Ka1 which has medium strength. RQD of Rd1 is excellent. Bd1 is poor whereas Rd2, Ka1 and Ch1 are fair. Three to four sets of joints are very common in the sample sites. Spacing of discontinuities is wide to close. Groundwater condition is dripping to completely dry. RMR value of the sampled site ranges from 39 to 66. The main reason behind low RMR (39) value of Ka1 is its groundwater condition. Rockmass condition of Rd1, Rd2, Bd1 and Ch1 is fair with RMR value 60, 50, 44 and 58, respectively.

Samples from the upper part of the Bhimphedi Group and the lower part of the Phulchoki Group include biotite schist of site Kh1 and Kh3 and augen gneiss (Kh2) of the Kulekhani Formation and metasiltstone (Ti1) of the Tistung Formation. Strength of the intact rock range from strong to extremely strong. RQD is very poor to Excellent. Spacing of the discontinuities is moderate to very close. Groundwater condition is wet to completely dry. RMR value ranges from fair to very good. Considering all the parameters, RMR value of Kh2 is found highest (82) of all the sampled site whereas rockmass conditions of Kh1, Kh3 and Ti1 ares fair with RMR value 47, 59 and 49, respectively.

Durability of Rock Aggregates

Aggregates are exposed to a number of physical and chemically degrading forces during processing, transporting, and construction. Hence aggregates must be clean, hard, sound, durable, resistant to abrasion, uniform in quality and free of any detrimental quantities of soft, friable, thin, elongated or laminated pieces, disintegrated material, and deleterious substances.

Toughness

Toughness indicates how much energy a material can absorb before rupturing. It can be defined as the ability of a material to absorb shock without breaking or shattering. All hard materials are not tough. In order to be tough a material must be strong and ductile. Aggregates which lack adequate toughness and abrasion resistance may cause construction and performance problems. Toughness of the rock aggregates can be accessed via index properties related to strength and resistance.

Index properties related to strength

Results of specific gravity, dry density, and porosity are shown in the Table 2 and that of point load index strength is given in the Table 3. Porosity is very important indicators for the utilization of various kinds of rocks (Christensen et al., 1996). Porosity of calcareous slate Bg2 (8.91%) is greatest among all the samples whereas smallest is 0.04% of Kh1 (Table 2). Porosity of low-grade metamorphic rock samples studied is comparatively more than that of other quartzite, schist and gneiss.

Dry density of aggregates used in construction is 2-3 g/cm^3 and average value is about 2.6 g/cm^3 used in road construction (ASTM, 1994). The dry density of Bg2 is lowest, i.e., 2.30 g/cm^3 and highest is of Kn2, i.e. 3.22 g/cm^3. Since density is not only the single parameter to determine the usage of the aggregates, the same rock has to perform better in all other physical and chemical test in order to use it for different construction purposes.

Specific gravity of all the rock is found to be in between the range of 2.08 to 3.08. The proportion of water absorbed by aggregate determines how much liquid the aggregate can absorb when soaked in water. 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% (Table 2). 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, 1989). So the rocks of location Bg1 and Bg2 are not suggested to use in concrete aggregate. WAV of low grade metamorphic rocks and slate is comparatively

Table 2: Determination of Specific Gravity, porosity, water absorption value and dry density

Sample	Specific Gravity	Dry density (g/cm³)	Porosity (%)	Water Absorption Value (%)
Kn1	2.69	2.73	0.94	0.53
Kn2	3.08	3.22	1.59	1.42
Fg1	2.7	2.73	0.57	0.32
Fg2	2.57	2.64	0.87	0.9
Da1	2.68	2.7	0.46	0.27
Np1	2.79	2.82	0.67	0.47
Np2	2.68	2.73	0.85	0.64
Np3	2.81	2.85	0.43	0.56
Dh1	2.75	2.81	1.32	0.86
Bg1	2.22	2.49	8.55	4.73
Bg2	2.08	2.3	8.91	4.75
Ml1	2.75	2.79	0.87	0.6
Ml2	2.81	2.82	0.19	0.12
Rb1	2.59	2.63	0.42	0.53
Rb2	2.66	2.67	0.24	0.15
Rb3	2.62	2.64	0.39	0.25
Rd1	2.72	2.76	0.79	0.43
Rd2	2.7	2.71	0.24	0.17
Bd1	2.95	2.97	0.76	0.26
Ka1	2.67	2.73	1.45	0.86
Ch1	2.65	2.66	0.32	0.22
Kh1	2.66	2.66	0.08	0.04
Kh2	2.54	2.63	2.35	1.34
Kh3	2.62	2.67	0.97	0.72
Ti1	2.67	2.72	0.85	0.75
L7	2.94	3	0.74	0.49

more than that of other quartzite, schist and gneiss.

Point load strength index

For aggregate, rock strength uniaxial compressive strength (UCS) value >100 Mpa is required. The point load index value of different lump samples were measured in a laboratory. The result comparing standard value (Bieniawski, 1975) is given in Table 3. The result of point load index value and UCS is lowest at the Benighat slate (Bg2) which was calculated to be 0.26 MPa and 5.9 MPa, respectively. Similarly, the highest value of point load index and UCS is found at the Robang quartzite (Rb1) which was calculated to be 13.13 MPa and 301.9 MPa, respectively (Table 4)

Table 3: Intact rock strength classification (Bieniawski, 1975)

UCS (MPa)	Strength classes	Sample number
>200	Very high strength	Rb1
100-200	High strength	Fg1, Fg2, Da1, Ml1, Rd2, Ka1, Ch1, Kh1,Kh3
50-100	Medium strength	Kn1, Np2, Np3, Rb3, Rd1
25-50	Low strength	Bg1, Ml2, Rb2, Bh1, Ti1
<25	Very low strength	Kn2, Np1, Dh1, Bg2, Kh2, L7

The rocks can be classified into five classes according to the intact rock strength classification given by Bieniawski (1975).

Resistance to Abrasion

Hardness (wearing property) and toughness (breaking property) of aggregates associated together are often carried out in Los Angeles test. The principle of the test is to obtain percent wear due to relative rubbing action between aggregates and steel balls used as an abrasive charge. Uniform factor and wear of gravel are determined by Los Angeles test (ASTM 1989). Results of Los Angeles test is shown in the Table 5.

The samples from 5 different locations were prepared in order to carry out Los Angeles abrasion test. The Los Angles abrasion values of the samples ranges from 19.6% to 47.5%. Though the sample Fg1 is quartzite, it has high abrasion loss percentage. Fg1 might have several non-connected pores and weak interlocking, hence couldn't bear impact load and abrasion. Np1 has low UCS but is less porous (0.67%) and has low water absorption value (0.47%) as well which could be the reason behind the low abrasion.

Resistance to Impact

The aggregate impact value is expressed as percentage by mass passing 2.36 mm sieve relative to the original mass. Aggregate Impact Value (AIV) below 10 percent is regarded as strong and AIV above 35 percent is normally regarded as too weak for use in road surface. The result of AIV of different rock samples is given in the Table 6.

The result of AIV ranges from 8.54 to 34.28% (Table 6). Impact Value (AIV) below 10 percent are regarded as strong and AIV above 35 percent would normally be regarded as too weak for use in road surface (ASTM, 1981). Hence, the rocks of Fg2, Da1, Np2, Np3, Ml1, Ml2, Rb2, Rd2, Bd1, Ka1, Ch1 and Kh1 are strong and resistant enough to withstand repeated and sudden impact load. Some are satisfactory whereas others are weak for pavement. Only the sample Np1 and Rb1 are found exceptionally strong. Sample Rb1 has low WAV (0.53%), high UCS (301.9 MPa) and is less porous (0.79%) which could be the reason behind such a low AIV whereas, sample Kh2 has very low UCS (19.2 MPa), comparatively high WAV (1.34%) and more porous (2.35%), which leads it to have such a high AIV as well. Impact loss of quartzite and dolomite samples seem to be low than others samples but loss of sample Fg1, Dh1 and Rb3 is unexpectedly more. The reason behind high loss could be weak interlocking and non-connected pores.

Soundness

Soundness test is a measure of how resistant an aggregate is to chemical weathering.

Sodium sulphate soundness value (SSSV)

Soundness test determines the resistance to disintegration of aggregates due to alternate cycles of dry and wet condition. The result of sodium sulphate soundness value (SSSV) with weight loss in each cycle along with the ratio of weight loss in first to last cycle is given in the Table 7 and Figs. 4 and 5. The percent loss after the five cycles is higher in Kn1, Bg2 and Kh2 compared to other samples (Fig. 4). Based on behaviour by percent loss of sample due to weathering in sulphate test, roughly four types of samples have been distinguished (Fig. 5).

(i) Samples showing gradual decrease in loss, i.e., initial high loss and low loss at the end of the cycle (Fig. 5a),

(ii) Samples showing more or less constant and negligible loss (Fig. 5b),

(iii) Samples showing high loss at the mid of the cylcle (Fig. 5c), and

(iv) Samples showing fluctuating high and low loss (Fig. 5d).

The result of test samples varies from 1.35% to 23.66%. The value below 12% is chemically sound (DOR, 2001 and NS: 297-1994) and above 10% is chemically unsound (ASTM C33, 1994). Np1 has low UCS but is less porous (0.67%) and has low water absorption value (0.47%) which could be the reason behind the low SSSV. Similarly, augen gneiss sample of the Kulekhani Formation (Kh2) has very low UCS (19.2 MPa), very high AIV (34.28%), comparatively high WAV (1.34%) and more porous (2.35%). Consequently, the sample Kh2 has very high SSSV too.

Ethylene Glycol soaking test

All the 25 lump samples were soaked for 30 days in the Ethylene Glycol solution and inspected after 1, 5, 10 and 20 days and the number (and location in the tray) of pieces of spalled (shed small fragments from their edges), fractured (split into two or three pieces) and disintegrated (spilt into more than 3 pieces) aggregate were recorded at each assessment but not any kinds of obvious effects were noticed within these periods. Hence, both the class value of the degree of disintegration and class value of time taken to develop the worst condition is 1. As a result soak test index becomes 2 for all the samples tested. Such types of results could be due to low proportion of swelling clays or due to low accessibility of ethylene glycol through the specimens due to low porosity. Therefore the samples are highly resistant to degradation.

Table 8 lists the specified values for various tests. Table 9 lists samples versus their suitability towards end-uses of construction aggregates.

DISCUSSIONS

The Lesser Himalaya of the central Nepal is mainly composed of sedimentary and metamorphic rocks. The wide range of metamorphic rock types is reflected in their variable usefulness as aggregate. Coarse- or medium-grained, massive, granular rocks such as quartzites, gneisses and marbles generally provide high quality aggregates, whereas foliated and platy rocks

Table 4: Determination of point load strength index (Is) and uniaxial compressive strength (UCS)

Sample	W_1 (mm)	W_2 (mm)	W (mm)	D (mm)	A (mm^2)	De^2 (mm^2)	P (KN)	I_s (KPa)	De (mm)	*F	$+I_{s(50)}$	#UCS	*Strength Classification
Kn1	47	55	51	56	2856	3636	10.5	2887	60.3	1.09	3.14	72.3	Medium strength
Kn2	45	60	52.5	41	2153	2741	1.75	639	52.35	1.02	0.65	15	Very low strength
Fg1	50	60	55	57	3135	3992	19.75	4948	63.18	1.11	5.5	126	High strength
Fg2	38	40	39	38	1482	1887	13	6889	43.44	0.94	6.47	149	High strength
Da1	58	55	56.5	45	2543	3237	21	6487	56.9	1.06	6.88	158	High strength
Np1	50	56	53	50	2650	3374	2.35	696	58.09	1.07	0.75	17.1	Very low strength
Np2	45	55	50	49	2450	3119	8.8	2821	55.85	1.05	2.97	68.2	Medium strength
Np3	48	54	51	30	1530	1948	4.5	2310	44.14	0.95	2.18	50.2	Medium strength
Dh1	50	30	40	55	2200	2801	2.75	982	52.93	1.03	1.01	23.2	Very low strength
Bg1	50	44	47	53	2491	3172	6.25	1971	56.32	1.05	2.08	47.8	Low strength
Bg2	55	58	56.5	62	3503	4460	1	224	66.78	1.14	0.26	5.9	Very low strength
Ml1	40	60	50	50	2500	3183	18.75	5890	56.42	1.06	6.22	143	High strength
Ml2	49	49	49	52	2548	3244	4.75	1464	56.96	1.06	1.55	35.7	Low strength
Rb1	52	40	46	32	1472	1874	26.25	14006	43.29	0.94	13.13	302	Very high strength
Rb2	47	52	49.5	50	2475	3151	3.75	1190	56.14	1.05	1.25	28.8	Low strength
Rb3	56	55	55.5	43	2387	3039	7	2304	55.12	1.04	2.41	55.4	Medium strength
Rd1	55	55	55	56	3080	3922	9	2295	62.62	1.11	2.54	58.4	Medium strength
Rd2	60	40	50	42	2100	2674	12.75	4768	51.71	1.02	4.84	111	High strength
Bd1	25	25	25	64	1600	2037	4.25	2086	45.14	0.95	1.99	45.8	Low strength
Ka1	55	50	52.5	40	2100	2674	17.5	6545	51.71	1.02	6.64	153	High strength
Ch1	50	46	48	51	2448	3117	19.25	6176	55.83	1.05	6.49	149	High strength
Kh1	52	65	58.5	43	2516	3203	14.25	4449	56.59	1.06	4.7	108	High strength
Kh2	60	65	62.5	45	2813	3581	2.75	768	59.84	1.08	0.83	19.2	Very low strength
Kh3	47	52	49.5	48	2376	3025	14.1	4661	55	1.04	4.87	112	High strength
Ti1	40	38	39	54	2106	2681	3.5	1305	51.78	1.02	1.33	30.5	Low strength
L7	45	45	45	55	2475	3151	1.25	397	56.14	1.05	0.42	9.6	Very low strength

Note: *F = $(De/50)^{0.45}$, $+I_{s(50)} = (F.\ I_s)/1000$ (MPa) and #UCS = $23.I_{s(50)}$ (MPa)

Table 5: Result of LA test

Sample no.	No. of spheres	No. of revolution	Total weight of Specimen, W_1 (gm)	Original weight of sample after the test retained on 1.7mm sieve, W_2 (gm)	*Abrasion (%)
Fg1	12	500	5000	2625	47.5
Np1	12	500	5000	4020	19.6
Np3	12	500	5000	3941	21.18
Ml1	12	500	5000	3307	33.86
Kh3	12	500	5000	3573	28.54

Table 6: Determination of aggregate impact value (AIV)

Formation	Sample no.	Rock type	Total Wt. W_1 (gm)	Wt. retained at 2.36mm sieve W_2 (gm)	*AIV (%)
Kuncha	Kn1	Mylonite	500	378.3	24.34
	Kn2	Phyllite	500	359.6	28.08
Fagfog	Fg1	Quartzite	500	399.4	20.12
	Fg2	Quartzite	500	445.3	10.94
Dandagoan	Da1	Phyllite	500	432	13.6
Nourpul	Np1	Siliceous Dolomite	500	450.5	9.9
	Np2	Quartzite	500	441.7	11.66
	Np3	Quartzite	500	447	10.6
Dhading dolomite	Dh1	Dolomite	500	346.4	30.72
Benighat slate	Bg1	Slate	500	350.2	29.96
	Bg2	Slate	500	357.1	28.58
Malekhu limestone	Ml1	Dolomite	500	445.4	10.92
	Ml2	Dolomite	500	414	17.2
Robang	Rb1	Psammatic Schist	500	457.3	8.54
	Rb2	Quartzite	500	416.5	16.7
	Rb3	Quartzite	500	383.7	23.26
	L7	Amphibolite	500	395	21
Raduwa	Rd1	Schist	500	396.6	20.68
	Rd2	Schist	500	410.9	17.82
Bhainsedovan	Bd1	Marble	500	443.4	11.32
Kalitar	Ka1	Schist	500	416.6	16.68
Chisapani Quartzite	Ch1	Quartzite	500	447.6	10.48
Kulekhani	Kh1	Biotite Schist	500	412.2	17.56
	Kh2	Augen gneiss	500	328.6	34.28
	kh3	Biotite Schist	500	405.2	18.96
Tistung	Ti1	Metasiltstone	500	382.2	23.56

Table 7: Determination of Sodium sulphate soundness value (SSSV)

Sample no.	Rock type	Initial weight W_i (gm)	After 1st cycle Weight (gm)	After 1st cycle Weight loss %	After 2nd cycle Weight (gm)	After 2nd cycle Weight loss %	After 3rd cycle Weight (gm)	After 3rd cycle Weight loss %	After 4th cycle Weight (gm)	After 4th cycle Weight loss %	After 5th cycle Weight W_f (gm)	After 5th cycle Weight loss %	*SSSV %
Kn1	Mylonite	400	392.01	1.99	385	1.79	383.58	0.36	377.05	1.7	372.22	1.28	7.12
Kn2	Phyllite	400	383.72	4.04	356.2	7.17	340	4.54	333.22	1.99	326.3	2.07	19.81
Fg1	Quartzite	400	382.48	4.38	377.71	1.24	375.66	0.54	373.12	0.67	370.56	0.68	7.51
Fg2	Quartzite	400	395.88	1.03	391.22	1.17	387.69	0.9	384.02	0.94	380.65	0.87	4.91
Da1	Phyllite	400	391.32	2.17	385.13	1.58	381.91	0.83	380.24	0.43	377.29	0.77	5.78
Np1	Siliceous Dolomite	400	397.99	0.5	396.1	0.47	395.8	0.07	393.14	0.67	390.6	0.64	2.35
Np2	Quartzite	400	391.09	2.22	386.24	1.24	383.99	0.58	383.13	0.22	381.65	0.38	4.64
Dh1	Dolomite	400	397.09	0.72	362.13	8.8	359.79	0.64	356.61	0.88	353.45	0.88	11.92
Bg1	Calcareous Slate	400	396.12	0.97	388.94	1.81	382.21	1.73	377.34	1.27	373.32	1.06	6.84
Bg2	Calcareous Slate	400	396.37	0.9	376.01	5.13	351.59	6.49	329.12	6.39	320.89	2.5	21.41
Ml1	Dolomite	400	387.89	3.02	382.55	1.37	382.01	0.14	372.12	2.58	370.13	0.53	7.64
Ml2	Dolomite	400	399.32	0.17	389.49	2.46	379.71	2.51	374.73	1.31	370.74	1.06	7.51
Rb1	Psammatic Schist	400	393.19	1.7	391.5	0.42	390.15	0.34	385.22	1.26	380.82	1.14	4.86
Rb2	Quartzite	400	392.81	1.79	386.77	1.53	385.32	0.37	380.36	1.28	378.31	0.53	5.5
Rb3	Quartzite	400	385.15	3.71	370.81	3.72	365.68	1.38	363.24	0.66	358.71	1.24	10.71
Rd1	Schist	400	396.01	0.99	387.91	2.04	386.03	0.48	378.87	1.85	372.52	1.67	7.03
Bd1	Marble	400	385.91	3.52	373.62	3.18	369.22	1.18	361.65	2.05	357.21	1.22	11.15
Ka1	Schist	400	398.29	0.42	397.46	0.2	388.31	2.3	381.81	1.67	373.23	2.24	6.83
Ch1	Quartzite	400	393.01	1.74	388.86	1.05	383.98	1.25	380.33	0.95	377.32	0.79	5.78
Kh1	Schist	400	378.68	5.33	370.41	2.18	367.92	0.67	364.35	0.97	361.64	0.74	9.89
Kh2	Augen gneiss	400	359.84	10.04	342.8	4.73	322.58	5.89	316.34	1.93	305.36	3.47	26.06
Ti1	Metasiltstone	400	392.27	1.93	389.02	0.82	383.42	1.43	372.21	2.98	365.88	1.7	8.86

such as schist and phyllites are usually weaker and are less durable. Sedimentary rocks such as limestones and dolomites are hard and durable for aggregates. They are common rock types and usually occur in thick beds which are structurally simple and easy to quarry. As a consequence, they are widely extracted for aggregates materials, as well as for cement manufacture (limestone only), and for industrial processes which utilize the chemical properties of the stone (Harrison, 1992).

Mylonite and phyllite samples were collected from the Kuncha Formation and phyllite sample from the

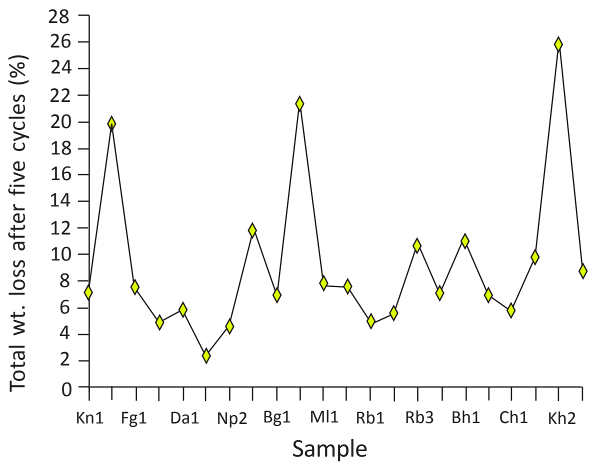

Fig. 4 Graphical representation of total weight loss of each sample after sodium sulphate soundness test.

Dandagaon Phyllite. Samples Kn1 and Kn2 resemble each other in most of the test performed except in UCS and SSSV. UCS and SSSV of Kn1 is far more better than that of Kn2. But if the phyllites of the Kuncha Formation and the Dandagoan Phyllites are compared then the performance of the Dandagoan Phyllite is better than that of the Kuncha phyllite in every test conducted. Porosity of 0.46%, UCS of 158.1 MPa, AIV of 13.6%, WAV of 0.27% and SSSV of 5.78% added more effectiveness towards toughness and soundness to the phyllite of the Dandagoan Phyllite.

Dolomite samples were collected from the Nourpul Formation, the Malekhu Limestone and the Dhading dolomite. UCS of Dh1 is 23.2 MPa whereas those of Ml1 and Ml2 are high. AIV and SSSV of Dh1 are higher than that of Ml1 and Ml2. With reference to the performance of samples, it can be concluded that the Malekhu Limestone is better in every respect than the Dhading Dolomite.

Altogether seven quartzite samples were collected and tested. If the quartzite samples from the Fagfog Quartzite are compared then the performance of both the samples is found almost same in every test except in impact test. Though the quartzite sample Fg1 has very good UCS but didn't performed well in impact test and abrasion test, sample Fg2 can be considered superior than Fg1. Al-Harthi (2001) tested Saudi Arabian rocks and correlated LA abrasion loss with both UCS and point load index. He showed that LA abrasion loss

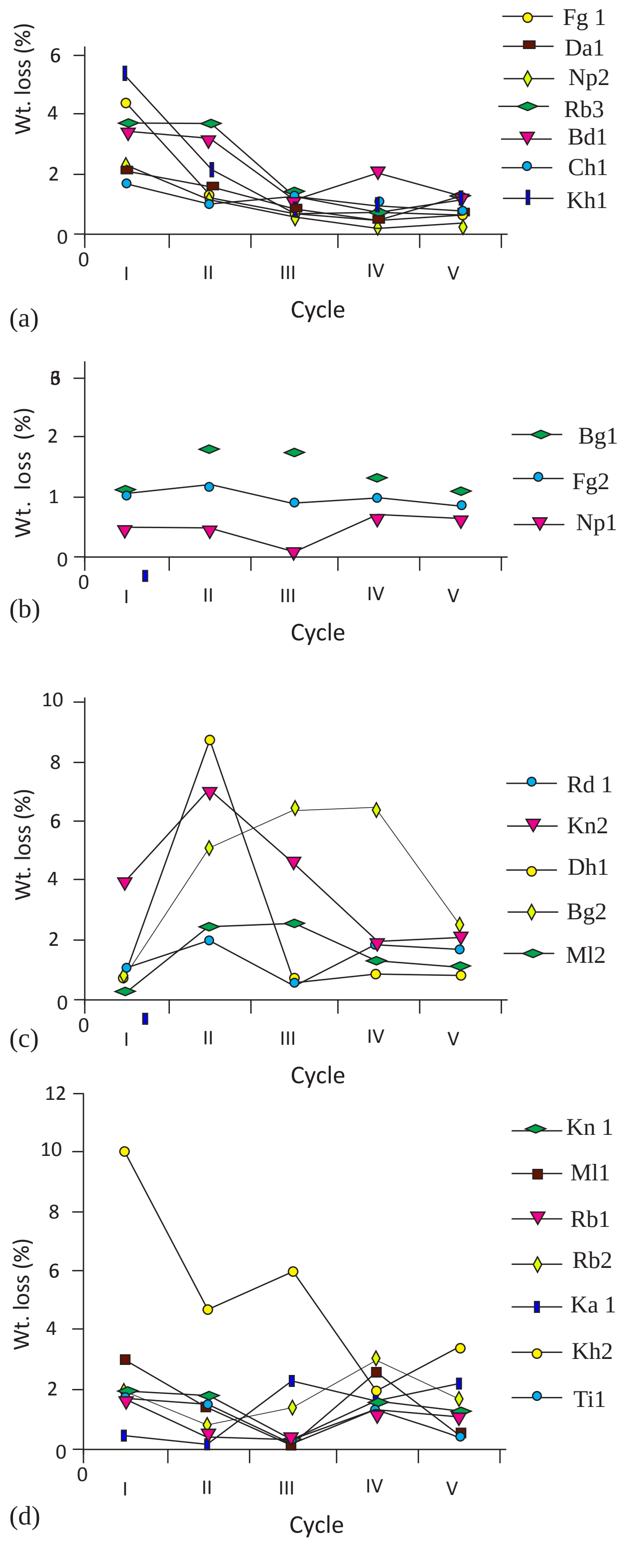

Fig 5: Weight loss behavior of degradation in each cycle during sodium sulphate soundness test. a) Curves of samples Fg1, Da1, Np2, Rb3, Bd1, Ch1 and Kh1, b) Curves of samples Bg1, Fg2, and Np1, c) Curves of samples Rd1, Kn2, Dh1, Bg2 and Ml2 and d) Curves samples of Kn1, Ml1, Rb1, Rb2, Ka1, Kh2 and Ti1

Table 8: Specifications of Various tests

Standards	Description
Water absorption value	
ASTM C 128/127	Generally, <2%, Not more than 2% for Riprap
AASTHO H 85	Generally, <5%
BS 812-2	Generally, <3%, 2% for roadstone aggregate. Not usually limited, but a recommended max. value of 2.5% is sometimes specified for concrete aggregate and less than 3% for filter aggregates.
Specifications of Sodium sulphate soundness test	
ASTM C33, 1994	Above 10% is chemically unsound 10% loss at 5 cycle (PCC, Asphalt), 12% loss at 5 cycle (surfacing and foundation courses), Armour coat
AASHTO T 104	<5%
Specifications of AIV	
ASTM, 1979	<10% (Exceptionally strong), 10-20% (Strong), 20-30% (Satisfactory for pavement surfacing) and >35% (Weak for pavement)
NS: 297-1994	<40% for wearing surface and <45% for normal concrete
BS 882: 1983	<25% for heavy-duty concrete floor finishes, <30% for concrete pavement wearing surfaces and <45% in other concrete
Los Angeles Abrasion Value	
AASHTO T 96	<40%for PCC and bituminous
ASTM C 131	<30% for Bituminous mix, <50% for base course and <16% for PCC
NS: 297-1994	<30% for Road and concrete structures, and <45% for others
DOR (2001)	<30-35% for Base course and <40% for Sub-base; For Bound MACADAM: <40% for Base and <45% for Sub Base

decreases with increasing UCS and point load index. Quartzite samples (Np2 and Np3) of the Nourpul Formation performed equally better in almost all the tests. But performance on index tests related to strength is almost same of all the samples. Hence, if the rocks from the Nourpul Formation have to be quarried, then the quartzite of location Np2 is appropriate. Two quartzite samples of the Robang Formation i.e Rb2 and Rb3 which has met the standards of all the specifications adopted. Hence, after following the standards of different specifications, the samples can be recommended for several construction purposes. With porosity of 0.32%, dry density 2.66 gm/cm^3, specific gravity 2.65, UCS of 149.3 MPa, AIV% and SSSV of 5.78%, Ch1 can be considered as one of the durable rock sample collected from the area. Hence, it can be recommended for different end uses.

Two representative slate samples were collected from the Benighat Slate. Strength of both the slate samples is low. Water absorption value and porosity is greatest among the entire samples. UCS of both the slates is also very low. Amah et al. (2012) studied basement rocks (South-Eastern Nigeria) for construction aggregates and found that moisture content (W%) increases with decreasing hardness (H), specific gravity (SG) and compressive strength except where rock weathering and underground water cause some adverse effects on the rock quality. A decrease in the compressive strength of rocks could also be attributed to the presence of fractures, joints or microcracks, arising from the geological cause such as pressure relief from erosion, and cementation from circulating ground water (Wang and Simmons, 1978). Weathering and structural defects (fractures/joints/microcracks) generally will decrease the strength of the material, accelerate the rate of alteration and increase the amount of saturation. RMR value of Bg1 and Bg2 is also very low i.e. 38 and 36 respectively. Normally, the rock aggregates having such mediocre performance are recommended for limited range of construction work adopting the standards of different specifications.

Altogether six schist samples were collected from the study area, one from the Robang Formation, two from the Raduwa Formation, two from the Kulekhani Formation and only one from the Kalitar Formation. Rb1 seems to be durable with UCS of 301.9 MPa, AIV

Table 9: Suitability of samples in terms of end-uses. The symbol v marks for suitability.

Sample	Rock type	Durability		Concrete aggregate	Filter aggregate	Pavement						Riprap
		Toughness	Soundness			Sub-base	Base	Wearing Surface	Asphalt pavement	Heavy-Duty concrete pavement		
Kn1	Mylonite	high	high	v	v			v	v	v		
Kn2	Phyllite	moderate	low		v							
Fg1	Quartzite	very high	high	v	v		v	v	v	v		v
Fg2	Quartzite	very high	high	v	v			v	v	v		v
Da1	Phyllite	high	high	v	v			v	v	v		v
Np1	Siliceous Dolomite	moderate	high	v	v	v	v	v	v	v		v
Np2	Quartzite	very high	high	v	v			v	v	v		v
Np3	Quartzite	very high	high	v	v	v	v	v		v		v
Dh1	Dolomite	moderate	moderate	v	v			v				v
Bg1	Slate	low	low									
Bg2	Slate	low	low									
Ml1	Dolomite	high	high	v	v	v	v	v	v	v		v
Ml2	Dolomite	high	high	v	v			v	v	v		v
Rb1	Psammatic Schist	high	high	v	v			v	v	v		v
Rb2	Quartzite	high	hgih	v	v			v	v	v		v
Rb3	Quartzite	high	high	v	v			v	v	v		v
Rd1	Schist	moderate	high	v	v			v	v	v		v
Rd2	Schist	moderate	high	v	v			v		v		v
Bd1	Marble	moderate	moderate	v	v			v	v	v		v
Ka1	Schist	moderate	high	v	v			v	v	v		v
Ch1	Quartzite	moderate	high	v	v			v	v	v		v
Kh1	Biotite Schist	moderate	moderate	v	v			v	v	v		v
Kh2	Augen gneiss	moderate	moderate	v	v			v				v
Kh3	Biotite Schist	high	high	v	v	v	v	v		v		v
Ti1	Metasiltstone	moderate	moderate	v	v			v	v	v		v

of 8.54% and 4.86% of SSSV. Rb1 meets the standard of all the specifications followed. Hence, it can be recommended for wide range of construction purposes. Garnetiferous schist of the Raduwa Formation also performed moderately in all the tests conducted. But the performance of garnetiferous schist of site Rd2 is better than Rd1 in every test.

Marble of the Bhaisedobhan Marble performed well in all test. Porosity of the sample is just 0.76% which also supported water absorption value. SSSV of the samples is also good. Hence, the sample of the Bhaisedobhan could be utilized for several purposes.

The Kulekhani augen gneiss has high strength but high porosity and water absorption value with average specific gravity and dry density. The sample is hard but not tough enough to react under sudden impacts. So, it has high impact loss.

The only sample of the Phulchauki Group was collected for the test of durability is Ti1 of the Tistung Formation. It is an average performer in the all the test. SSSV of 8.86% supported it in durability but AIV and UCS put it behind other samples. So, the sample Ti1 could be recommended only for fewer end uses.

CONCLUSIONS

The study area comprises sedimentary and metamorphic rocks. Slate, phyllite, schist, quartzite, marble, and augen gneiss are the metamorphic rocks and dolomite and is the sedimentary rock found in the study area.

Most of the rockmass of the study area is in dry condition but wet and dripping rockmass condition is also common in some rockmass. Three to four major joint sets are common in the area with smooth to rough surface. The rocks of the area are found slightly to moderately weathered, thin to thick bedded with gentle topography. RMR values of the rockmass containing quartzites are comparatively more than the rockmass containing other rock type. RMR value of the study area is found between fair to good. The only augen gneiss sample of the Kulekhani Formation has the excellent RMR value.

Specific gravity ranges from 2.08 to 3.08 and the dry density ranges 2.3 to 3.22 g/cm^3. All the samples have porosity less than 2% except the samples of the Benighat Slate. Bg1 and Bg2 have porosity 8.55% and 8.9% respectively. UCS value ranges from 5.9 MPa to 301.9 MPa. Psammatic schist of the Robang Formation has the highest UCS. The LA abrasion percentage is greatest of quartzite the Fagfog Quartzite (Fg2) and lowest of siliceous dolomite of the Nourpul Formation. Aggregate impact value (AIV) of psammatic schist (Rb1) is lowest and highest of augen gneiss (Kh2). With all the results of index properties along with LA test, it can be concluded that the rocks of the area are tough enough to resist the impact load.

The SSSV of three samples Kn2, Bg2 and Kh2 are greater than 12% hence does not meet the criteria for any end uses. But all other samples are chemically sound and resistance against weathering and frost susceptibility.

WAV of all the samples is below 2% except Bg1 (4.73%) and Bg2 (4.75%), which indicates that the aggregates have low effective porosity.

Ethylene glycol soaking test also shows that proportion of swelling clays and accessibility through samples is low. Most of the sample meets the standards of the different specifications.

In reference to the rockmass condition and the performance of samples in different test, it can be concluded that most of the rocks of the Lesser Himalaya of Malekhu area are durable enough to recommend for wide range of end uses adopting the standards of different specifications. Quartzites, siliceous dolomites and psammatic schists are found to be more suitable for construction aggregates compared to slate, phyllite, metasandstone, and gneiss.

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