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Physical, mechanical and petrographic properties of Lesser Himalayan rocks from Kavre area: An assessment of quality for concrete aggregate

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ABSTRACT

With rapidly growing population, development of human civilization and increasing construction of infrastructures, the demand of aggregate is increasing day by day. The quarries of naturally occurring sand and gravel are not sufficient to fulfill the demand, and are disturbing the river environments. Therefore, the crushed-rock aggregates should be used to meet the requirements. The accessible resources, quality and quantity for aggregates play an important role in the durability of roads, buildings, projects, many other infrastructures and sustainable development. Negligence of quality of aggregates would lead to rapid degradation of concrete structures. Therefore, being aware of these things, quality of aggregates should be prioritized. The exploration of outcrops from which suitable aggregates can be exploited is essential. This study aims to explore and evaluate the resources and quality of crushed-rock aggregates from the Lesser Himalayan rocks in the Kavre area.

Different kinds of rocks were identified from the outcrop in the study area: quartzite, psammitic schist, calc-quartzite, metasandstone and metasiltstone. Thirteen representative samples were taken from different lithological formations. The water absorption value (WAV) of samples ranges from 0.302 to 2.393%. Dry density varies from 2.308 to 2.743 gm/cm3 and the uniaxial compressive strength value ranges from 23.62 to 217.92 MPa. In general, these values indicate that the aggregates are compact and strong. The aggregate crushing value (ACV) ranges from 19.56 to 35.4% and the aggregate impact value (AIV) ranges from 11.02 to 23.84% showing that the aggregates are resistant against compressive load and strong against impact load. The sodium sulphate soundness value (SSSV) lies between 5.95 to 16.66% and methylene blue absorption values (MBAV) in all samples are <1% indicating that the samples are durable and chemically sound. The alkali silica reactive features, swelling and expanding clay minerals like chert, opal, high-quartz, extremely deformed fractured quartz, smectite, and kaolinite are absent. Though some quartz grains are undulosed and fractured, they are mega and low-quartz. Only the clay mineral illite, 1M type is present in very small proportion. All these parameters show that the samples of the Lesser Himalayan rocks from the Kavre area are suitable and acceptable for concrete aggregates of general.

Key words: Lesser Himalaya, aggregates, rock mass rating, aggregate crushing value, sodium sulphate soundness value, petrography

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INTRODUCTION

Infrastructures in the country are increasing day by day due to rapid growth of population. The demand of construction material has also increased. Rocks and sediments are main sources of construction materials, which are used as paving floors, roofing, concrete aggregate and road aggregate. Quality of aggregates used in concrete structures is of great concerns. Several lab tests and analyses are made to characterize the physical, mechanical, chemical and petrographic properties of these aggregates. Unfortunately, there is a growing practice of infrastructure construction without following the specification or the standard of materials used. The quality of aggregates should be kept at high priority. As naturally occurring sand and gravel are not sufficient to fulfill the demand in the city, and river quarrying is disturbing the river environment, crushed-stone aggregates should be used to meet the requirements. Most of the crushed-stone (aggregate) is supplied from Kavre area in Kathmandu and Banepa valley. The Precambrian to Paleozoic rocks of the Kathmandu Complex (Stöcklin 1980) are the major sources of aggregate in Kavre, Dhading, Makawanpur and many other parts of the country. The high potential areas for concrete aggregate are mainly located along the BP Highway, Araniko Highway and surrounding area in Kavre area. The location of the study area is shown in Fig. 1. The best selection of rocks for aggregate depends on properties and set by national and international specifications. The widely accepted standards are American standard of testing materials (ASTM) and British standard (BS). The Indian standard (IS) is also accepted in Nepal. Department of Road (DOR) Nepal (2001) published standard specification for road, bridge and pavement structures. Tamrakar et al. (2002), Maharjan and Tamrakar (2003), Dhakal et al. (2006), Khanal and Tamrakar (2009), and Tamrakar and Paudel (2011) analysed various rocks for concrete, road and pavement aggregates.

METHODOLOGY

The 1:25000 scale topographic maps was used for geological mapping. Various rock types were mapped along with their attitudes and descriptions. Samples for microscopic study and laboratory testing were also collected. The engineering geological study of the rock outcrops, the lithological characteristics, rock mass properties, weathering grade, and indurations were studied during the fieldwork. The rock outcrops were classified according to the rock mass rating (RMR) system (Bieniawski 1989). The representative samples of different rock types from different lithological formations having 8 to 10 Kg per station were collected for the laboratory study. This study discusses the tests of crushed rock aggregates by some physical, mechanical, chemical and petrographic parameters.

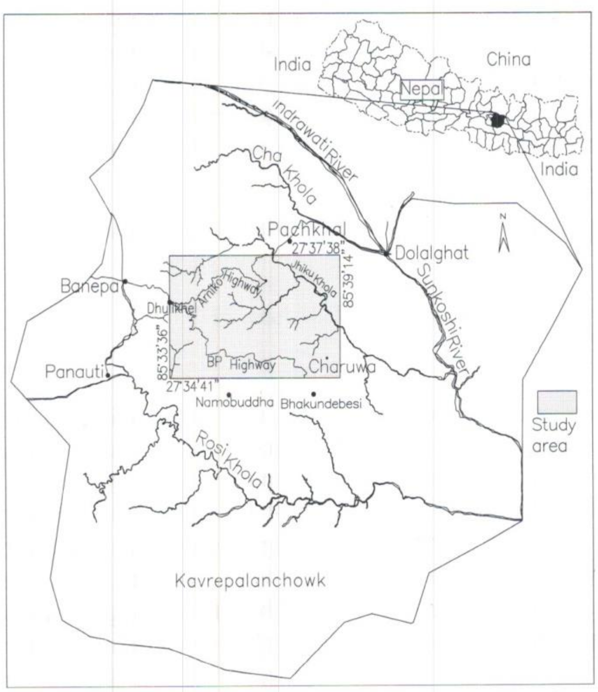

Fig. 1: Location map of the study area.

From the block of samples two sets of cores of diameter 2.51 cm and 4.5 cm long were drilled out in the laboratory. One set sample was used for testing point-load strength index and another set of core sample was used to determine the water absorption and dry density. The water absorption value was determined by measuring the increase in sample weight owing to pore-water according to Caliper and saturation method (ISRM 1979). The samples were prepared for mechanical test using hammer, sieves of size 25 mm and 20 mm for aggregate crushing value (ACV) and 12.5 mm and 10 mm sieve for Aggregate Impact Value (AIV). The tests for durability against weathering and assessment of clay minerals were also made. The sodium sulphate soundness test was done following ASTM Designation C88–05 (ASTM 2005). The methylene blue absorption test was used to test soundness of aggregates by determining existence of swelling clays like smectite according to Hills and Pttifer (1985).

Thirteen thin sections were examined for the petrographic properties of aggregate, alkali-silica reactivity analysis considering ASTM Designation C295–03 (ASTM, 2003). Samples having Very fine-grained (<15 μm) quartz and visible clay matrix were selected for the XRD analysis after examining in the petrographic microscope. The reactive silica and harmful clay minerals present in the aggregate were studied by means of X-ray diffractometry. The air dried samples were used in XRD analysis (Bruker's D8 advance diffractometer, computer controlled). The scan range for bulk mineralogy were 2–40 2θ at a speed of 2°/min and 20–22 2θ at a speed of 0.5°/min for detection of silica and 4–14 2θ at a speed of 0.5°/min for the detection of clay minerals. The peaks of diffractograms obtained from scanning silica and clay were compared with the curves of opal, chalcedony, tridymite, micro-quartz, crystobalite, illite, smectite, kaolinite and chlorite to analyse their presence in the samples.

GEOLOGICAL SETTING

The rocks of the Kavre area can be assigned in to the Kathmandu Complex and the Nawakot Complex. These two Complexes are distinctly separated by the Chak–Roshi Thrust which is a part of the Mahabharat Thrust (Stöcklin and Bhattarai 1977; Stöcklin 1980). Tamrakar et al. (1997) prepared a geological map of the Jhiku Khola watershed area, and generalized lithostrtigraphic column of the Lesser Himalayan rocks in the Kavre area. Paudel and Tamrakar (2012) studied the geology and rock mass characteristics of the Dhulikhel-Panchkhal area. The stratigraphic subdivision of the area is given in Table 1 and the geological map of the study area is shown in Fig. 2.

Table 1: Stratigraphic sub–divisions of the Kavre area, central Nepal Lesser Himalaya (based on Stöcklin 1980).

Complex	Group	Formation	Main lithology	Thickness (m)	Age
Quaternary Deposit			Fine sediments of sand, silt and clayey. The gravel, pebbles to boulder size sediments	-	-
Kathmandu Complex	Phulchauki Group	Tistung Formation	fine clastic sequence of metasandstone, siltstone, phyllite and slate	>1000	Early Cambrian, Late Precambrian
	Bhimphedi Group	Timaldanda Granite Gneiss	Foliated gneiss and augengneiss consists of quartz, feldspar, biotite, muscovite and tourmalline. Grey with white spots, coarse grained, porphyroblast augen structure of feldspar and quartz	-	-
		Markhu Formation	Greenish grey to light grey, medium to massive bedded, fine to medium grained calcareous schist and micaceous calcareous quartzite	1200	Late Precambrian
		Kulekhani Formation	Laminated, competent, dark grey, finely crystalline micaceous quartzite and schist. Tourmaline, pegmatite and quartz veins	1250	Precambrian
		Chisapani Quartzite	Thin to thick bedded continuous bands of white crystalline slabby quartzite and thin to medium bands of mica schist are also intercalated	400	
		Kalitar Formation	Medium to coarsely crystalline showing good schistosity schist and intercalated with quartzite. Biotite, muscovite, sericite and chlorite are present	800	
		Bhainsedobhan Marble	Thin to medium bedded, laminated, coarsely crystalline, grey to white marble and thin to medium bedded, dark grey calcareous, mica bearing quartzite	260	
		Raduwa Formation	Garnetiferous micaschist, micaschist with some micaceous quartzite.	200	
			Chak-Rosi Thrust (Mahabharat Thrust)		
Nawakot Complex	Upper Nawakot Group	Benighat Slates	Black carbonaceous slate, phyllite and calcareous phyllite and quartzite, laminated light gray and porous limestones	>200	Early Paleozoic

Mainly the Bhimphedi group and the lower unit of the Phulchoki group (i.e., Tistung Formation) of the Kathmandu Complex are distributed in the study area. Small part of the upper unit of the Upper Nawakot Group (i.e., Benighat Slate) is also exposed in the footwall of the Chak-Rosi Thrust at the NE of the study area. The essential lithological differences between the Kathmandu and the Nawakot Complexes are the metamorphic grade. The Kathmandu Complex consists of relatively high-grade metamorphic rocks such as garnetiferous mica schist, micaceous quartzite and calcareous schist. The Timaldanda Granite Gneiss is intruded within the Bhimphedi Group at the SE part of the study area. The unmetamorphosed or weakly metamorphosed rocks of the Tistung Formation of the Phulchouki Group are well exposed at the western part of the study area. The valley filling soft sediment is also widely distributed in the present study area. The major attitudes of strata extend NW–SE and dip SW.

ROCK MASS CHARACTERISTICS

Discontinuity characteristics

The rock mass characteristics were measured at thirteen locations of different lithological formations. Three major joint sets with parallel to bedding plane were found. Most of the bedding joints are dipping towards southwest. The other major joint sets are oblique to perpendicular with bedding joints at almost all locations. Most of the bedding and foliations contain close to moderate (6-60 cm) spacing. These types of spacing distribute the rock mass into number of blocks. Almost all the persistency of beddings are high to very high (10 m to >20 m). It defines low stability of rock mass that becomes easy to excavate. The presence of more joints and fractures is favourable for aggregate excavation.

Discontinuity surfaces are smooth to rough. Bedding and foliation roughness is relatively slightly smooth than other joint planes. The joint apertures are moderate open to wide (0.1 mm to 1 cm). The most of the infill materials are clay, silt with organic matters and vegetation. The weathering grade of rocks was classified according to weathering classification (GSL, 1977). Most of the rocks on the outer surface are faintly weathered to slightly weathered. Rocks are weakly indurated to strongly indurated according to the criteria of Larson et al. (1995).

Rock mass classification

The rock mass in the study area are classified into fair rock and good rock class according to the RMR system (Bieniawski 1989) shown in Table 2. The rock masses at the locations KV9, KV3, KV13, KV11 and KV12 are fair rocks and at the location KV8, KV7, KV6, KV10, KV5,

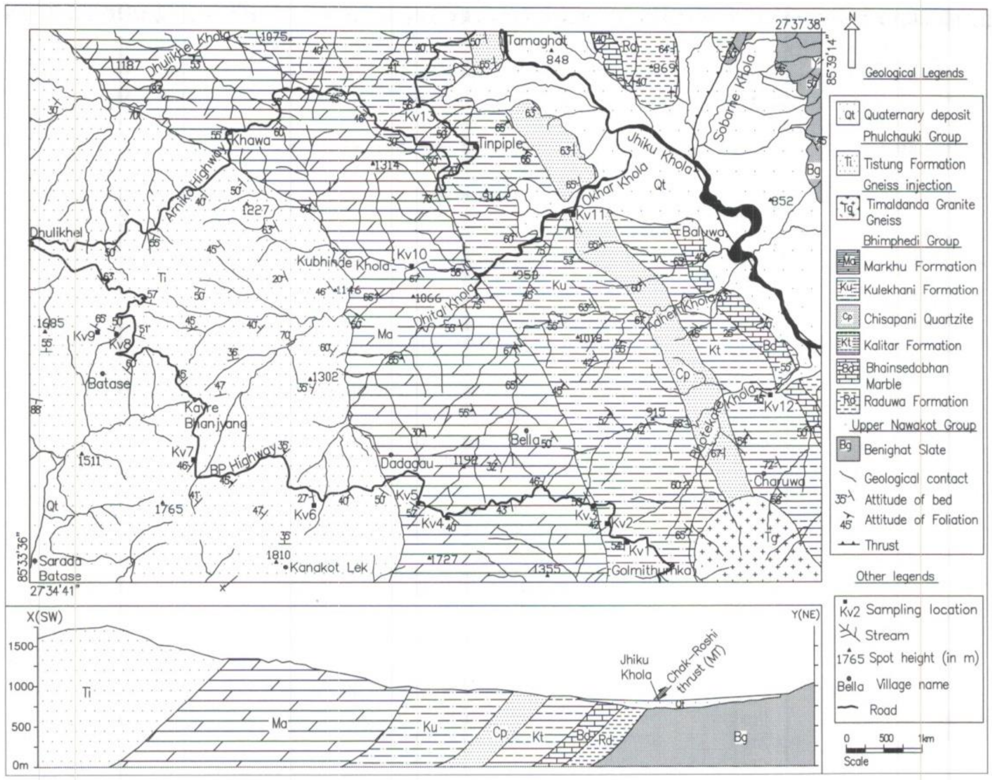

Fig. 2: Geological map of the Kavre area, central Nepal Lesser Himalaya (Compiled after Tamrakar et al. 1997).

KV4 and KV2 are good rocks. The RMR values for the meta-siltstone (KV9) and micaceous white quartzite of the Kalitar Formation are minimum. Due to the effect of the ground water condition, low spacing and rock quality designation (RQD) rating (Jv is greater), the RMR at KV12 is minimum. Although the effect of ground water condition, all the parameters are strong for the calcareous quartzite at the location KV10, the RMR value is maximum.

PROPERTIES OF AGGREGATES

The physical properties of aggregates are those that refer to the physical structures of the particles that make up the aggregate. The strength, elasticity and abrasion are performed by the mechanical properties. The soundness workability and durability of aggregates can be determined by some chemical tests. The compositional constituents, alkali-silica reactivity and impurities are also the important parameters. Among them some properties were studied separately with their standard consideration (Table 3).

Physical properties

The measured WAV ranges from 0.302 to 2.392%. The data show that the rocks are compact enough with negligible pores, and are suitable for aggregate (ASTM 1989). Strong aggregates have a very low WAV (<1%). The WAV above 4% needs further test on the aggregate to determine its acceptability. The calculated dry density ranges from 2.308 to 2.743 gm/cm^3, and rocks. The dry density of aggregates normally used in construction is 2–3 gm/cm^3 and average value of about 2.6 gm/cm^3 is in road construction (ASTM 1994).

Mechanical properties

The calculated ACV ranges from 19.56% to 35.4%. The ACV up to 30 % is mechanically sound for road aggregate and up to 45% is satisfactory for use in other concrete aggregate (NS 1994). The rock samples KV3 and KV9 are weak to resist crushing. The others are stronger and mechanically sound. The result of AIV ranges from 11.02 to 23.84%. The AIV lying between 10 and 20% is considered strong (NS 1994). The AIV between 20 and 30% is satisfactory. Therefore, both ACV and AIV agree with the standard values and indicate that some rocks are strong (KV8, KV7, KV6, KV10, KV5, KV4 and KV1) and some are satisfactory (KV9, KV3, KV13, KV2, KV11 and KV12) to resist impact.

Chemical properties

The sound aggregates are generally durable. Five soaking

Table 2: Determination of weathering grade, induration, uniaxial compressive strength and rock mass classification.

Formation	Location	Rock type	*Weathering grade	+Induration	UCS (MPa)	RQD (%)	RMR	×Rock class
Tistung	KV9	Meta-siltstone	Ib to II	H2 to H3	23.63	58.9	50	III
	KV8	Meta-sandstone	Ib	H3 to H4	142.56	52.3	68	II
	KV7	Meta-sandstone	Ib	H4	152.95	68.8	65	II
	KV6	Meta-sandstone	Ib to II	H3 to H4	217.92	65.5	63	II
Markhu	KV10	Calc-quartzite	Ib	H4	132.57	75.4	69	II
	KV5	Schist	Ib to II	H3 to H4	185.37	68.8	65	II
	KV4	Quartzite	Ib to II	H3 to H4	108.85	58.9	64	II
	KV3	Schist	II	H2 to H4	43.57	68.8	58	III
Kulekhani	KV13	Schist	II	H3	83.07	72.1	54	III
	KV2	Schist	Ib to II	H4	127.45	58.9	66	II
	KV1	Schist	Ib	H3 to H4	105.47	68.8	62	II
Chisapani Quartzite	KV11	Quartzite	Ib and II	H3	188.55	49	57	III
Kalitar	KV12	Quartzite	II	H3	140.33	45.7	50	III

*Weathering grade: Ib = faintly weathered, II = slightly weathered (after Geological soc. London 1977). +Induration: H2 = weakly indurated, H3 = indurate, H4 = strongly indurated (after Larsen et al. 1995). ×Rock mass rating system (Bieniawski 1989).

Table 3: Result of physical, mechanical and chemical test for aggregates.

Formation	Sample no.	Rock type	WAV (%)	Dry density (gm/cm^3)	ACV (%)	AIV (%)	SSSV (%)	MBAV (%)
Tistung	KV9	Meta-siltstone	0.739	2.591	35.4	20.76	16.66	0.83
	KV8	Meta-sandstone	0.450	2.658	24.83	17.12	7.93	0.67
	KV7	Meta-sandstone	0.586	2.525	22.73	15.01	10.71	0.50
	KV6	Meta-sandstone	0.902	2.308	21	12.49	10.44	0.67
Markhu	KV10	Calc-quartzite	1.189	2.483	21.4	15.55	13.28	0.67
	KV5	Schist	0.327	2.743	19.56	11.02	10.26	0.50
	KV4	Quartzite	0.302	2.673	22	16.12	9.91	0.67
	KV3	Schist	2.392	2.359	30.5	23.67	11.02	0.50
Kulekhani	KV13	Schist	0.401	2.735	23.16	23.84	5.95	0.50
	KV2	Schist	0.691	2.645	23	23.31	9.97	0.67
	KV1	Schist	0.488	2.644	22.16	19.29	9.97	0.67
Chisapani Quartzite	KV11	Quartzite	0.405	2.569	24.66	22.43	12.08	0.50
Kalitar	KV12	Quartzite	0.357	2.599	25.66	22.64	12.55	0.50

and drying cycles were carried out in sodium sulphate soundness test. The result of sodium sulphate soundness value (SSSV) varies from 5.95 to 16.66%. The value below the 12% is chemically sound (ASTM C88–05; NS 1994). The metasiltstone of the Tistung Formation (KV9), quartzite of the Markhu Formation (KV10), micaceous quartzite of Chisapani Quartzite (KV11) and quartzite of Kalitar Formation (KV12) are chemically fair as they possess SSSV >12%. Other samples being durable, show their resistance to frost weathering. The methylene blue absorption value

(MBAV) in all samples is less than 1%. It shows that the swelling clay minerals and organic matters are negligible, and aggregates from these rocks can perform well.

Petrographic properties

The petrographic studies gave the relative amount of the constituents, their physical and mineralogical characteristics. Some selected samples were analysed further in XRD after they were examined under a polarizing microscope. The results of textural and compositional analyses of samples are given in Table 4 and Table 5, respectively.

Quartz grains are predominant (52 to 81 %) in the sample no. KV4, KV6, KV7, KV8, KV9, KV11 and KV12. Feldspar grains are very less (<7%) in proportion in all samples. Mica (biotite and muscovite) grains are greater or nearly equal with quartz grains in sample no. KV5, KV1, KV2, KV3, KV5 and KV13. Due to the high mica in these samples, rocks tend to split along foliation. The chlorite in metasandstone and in schist are very less in proportion (<5%). Some calcite grains are seen in sample KV3 and KV10. The other minerals include heavy minerals, opaque

Table 4: Textural and microstructural studies of samples from thin section.

Formation	Sample no.	Mean grain size (μm)	Grain shape	Texture	Fabric: Homogenity	Fabric: Microfabric	Deformation
Tistung	KV9	47	Subangular, subhedral, elongated mica	Moderately sorted, submature	Homogeneous	Microlaminae, floating , point and tangential contact	Slightly deformed, 1 set foliation
	KV8	71	Rounded to angular, elongated mica	Moderately sorted, relict	Homogeneous	Microlaminae, tangential contact	Slightly deformed, 1 set foliation
	KV7	73	Subangular–rounded, elongated mica	Moderately sorted	Homogeneous	Microlaminae, tangential to concavo–convex contact	Slightly deformed
	KV6	98	Anhedral – subhedal	Moderately sorted, mature, relict	Heterogeneous	Massive, point to suture contact	Slightly deformed, 1 set foliation
Markhu	KV10	81	Subhedral – anhedral, angular	Granoblastic	Heterogeneous, patches	Massive, polycrystalline, tangential contact	1 set foliation
	KV5	69	Anhedral, elongated mica	Lepidoblastic, crenulated	Heterogeneous	Mica fish, polycrystalline, microlaminnae	2 set foliation
	KV4	101	Anhedral	Granoblastic	Homogeneous	Massive, suture contact	1 set foliation
	KV3	94	Anhedral	Granoblastic	Heterogeneous	Massive, indented–sutured contact	1 set foliation
Kulekhani	KV13	242	Anhedral, elongated	Porphyritic,	Heterogeneous	Massive, mica fish, sutured contact	2 set foliation
	KV2	99	Anhedral	Granoblastic	Heterogeneous	Massive, polycrystanlline	2 set foliation
	KV1	106	Anhedral, elongated	Lepidoblastic crenulated	Heterogeneous	Tangential to suture contact, microlaminae	2 set foliation
Chisapani Quartzite	KV11	330	Anhedral	Porphyritic	Heterogeneous	Massive, sutured contact	1set foliation
Kalitar	KV12	272	Anhedral	Porphyritic	Heterogeneous	Massive, suture, tangential contact	1set foliation

Table 5: Compositional analysis of rock samples obtained from thin section studies.

Sample no.	Composition of the rock samples (%)								*Ipw	Description
	Quartz	Feldspar	Biotite	Muscovite	Sericite	Calcite	Chlorite	Other		
KV9	58	4	–	17	8	–	3	9	0.11	Metasiltstone
KV8	62	6	–	16	7	–	3	9	0.09	Metasandstone
KV7	60	7	–	15	8	–	5	5	0.09	Metasandstone
KV6	59	3	13	12	3	–	3	5	0.11	Metasandstone
KV10	44	3	34	9	–	5	–	5	0.10	Quartzite
KV5	37	3	32	22	–	–	3	3	0.22	Schist
KV4	52	3	28	11	–	–	2	4	0.18	Micaceous quartzite
KV3	41	7	33	12	–	2	1	4	0.14	Schist
KV13	29	4	37	23	–	–	3	4	0.19	Schist
KV2	42	1	37	15	–	–	2	3	0.14	Schist
KV1	41	3	31	18	–	–	1	6	0.19	Schist
KV11	81	2	2	11	–	–	–	4	0.14	Micaceous quartzite
KV12	74	1	14	9	–	–	–	2	0.16	Micaceous quartzite

*Ipw (Petrographic weathering) = WP/1-WP and WP is % of weathered minerals.

minerals and unidentified minerals. The petrographic weathering index varies from 0.09 to 0.22. It shows that the presences of weathered minerals grains are very low. The photomicrographs are shown in Figs 3-8.

The petrographic study shows that the tectosilicate minerals are greater than phylosilicate minerals in proportion on quartzite, meta-sandstone and meta-siltstone. Its proportion is slightly lower on psammitic schist. The mineral grains are indented and suture contact between the mineral grains shows the strong interlocking. The reactive silica are absent in all samples. Only the clay minerals illite and chlorite are present which are not more deleterious as they occur in less than 5%.

Alkali–silica reactivity

Six samples having fine-grained size were selected after petrograhic study for further analysis using X–Ray difractometry. The result is shown in the Table 6. Very fine quartz grains (<15 μm) are present in metasiltstone (KV9), metasandstone (KV7) and psammitic schist (KV5, KV2). All the quartz grains are entirely low-T quartz. The fracture in quartz grains may be reactive (KV11, KV12). Some quartz–feldspar grains in other samples exhibit slight fractures. The deleterious clay minerals are not found in the samples. The diffractograms show only presence of illite, 1M. The illite, 1M is a structural polytype in which sticking pattern is linear and unidirectional. It is not more harmful than smectite and kaolinite clay. The reactive silica and harmful clay minerals are therefore absent in the rock samples. Considering fracture and undulation in quartzite rock, the alkali–silica reactive potential is negligible.

EVALUATION OF ROCKS FOR CONCRETE AGGREGATE

The evaluation of rocks for concrete aggregate comparing with existing standard is summarised into Table 7. All the samples of rocks can be categorised into the following types based on field and laboratory analyses:

A. Metasandstone and calc-quartzite (KV6, KV7, KV8, KV10)

B. Micaceous quartzite (KV4, KV11, KV12)

C. Psammitic schist (KV5, KV3, KV2, KV1, KV13)

D. Metasiltstone (KV9)

The rock categories A, B and C are nearly similar with their physical, mechanical and chemical properties, and only the petrographic properties are quite difference. Only the category D (meta-siltstone, KV9) is quite difference mechanically, chemically and petrographically than others. The WAV, dry density and MBAV are average and meet the existing standard value for concrete aggregate in all samples. Alkali-silica reactive parameters are negligible and the presence of deleterious materials like clay (illite), chlorite and mica in almost all samples is little and other harmful swelling clay minerals (smectite) are absent. Therefore the rock samples have very low alkali-silica reactivity.

Table 6: Alkali–silica reactive parameters present in the rock samples.

Sample no.	Sampling site	Rock type/ Geological Formation	Texture in thin-section	Fine-grained quartz (<15μm)	Quartz type	Fracture	Reactive silica	Clay minerals
Kv9*	Up hillside of the BP Highway, about 3.5km from the Dhulikhel	Metasiltstone/ Tistung Formation	The grains are moderately sorted, submature and slightly oriented. The slightly 1 set deformation is developed (Fig. 3).	Present	Low quartz	Slight	Absent	+Illite,1M
Kv8	Up hillside of the BP Highway, about 5km from the Dhulikhel	Metasandstone / Tistung Formation	Rounded to angular grains of quartz and feldspars are moderately sorted, relict. 1 set of slightly deformation is developed	Absent	Low quartz	Slight	Absent	-
Kv7*	BP Highway, about 1km from the Kavrebhanjyang towards the Dadagau.	Metasandstone / Tistung Formation	Fine grained moderately sorted, equigranular quartz grains with elongated chlorite that poorly defines foliation; Some mud and silt matrix are also visible; Preferred orientation of muscovite and sericite (Fig. 4).	present	Low quartz	Slight	Absent	+Illite,1M
Kv6	Uphill side of BP Highway, near the Hanumanthan school	Metasandstone / Tistung Formation	The grains are moderately sorted, mature, point to suture contact. Anhedral and subhedral grains are slightly 1 set deformed.	Absent	Low quartz	Slight	Absent	-
Kv10	Left bank of Kubinde Khola about 1km upstream from the confluence of Kubinde Khola and Dhital Khola	Calc. quartzite/ Marhu Formation	One set deformation, massive polycrystalline, subhedral to anhedral, angular grains of quartz are observed.	Absent	Low quartz	Slight	Absent	-
Kv5*	Uphill side of BP Highway, near the Dadagau village	Psammitic schist/ Markhu Formation	Two set deformation, crenulated structure, preferred orientation of mica grains, mica fish, polycrystalline, microlaminnae are present.	Present	Low quartz	Moderately	Absent	+Illite,1M
Kv4	BP Highway, about 1km from the Belldada towards Dadagau	Micaceous quartzite/ Markhu Formation	Quartz and feldspar grains are equant and anhedral, homogenous fabric, 1 set of deformation is developed indicated by strong orientation of mica grains.	Absent	Low quartz	Slight	Absent	-
Kv3*	Up hillside of the BP Highway, near the Bella village	Psammitic schist/ Markhu Formation	One set deformation is clearly observed by preferred orientation of the mica grains (Fig. 5)	Absent	Low quartz	Slight	Absent	+Illite,1M
Kv13	Uphill side of Arniko Highway, 1km from Tinpiple to Tamaghat at stream channel	Psammitic schist/ Kulekhani Formation	Recrystallized quartz and fenlspar grains are subhedral to anhedral and mica are niddle shaped. 2 set of strong deformation is cleared. Suture and indented contact among quartz grains and deformation bands are prominent.	Absent	Low quartz	Moderately	Absent	-
Kv2*	Uphill side of BP Highway, about 2km from the Golmithumka to Bella village.	Psammitic schist/ Kulekhani Formation	Two-set of foliation, edge of mica grains are altered to cholorite. Cross cut mica and heterogeneous distribution with quartz.	Present	Low quartz	Slightly	Absent	+Illite,1M
Kv1*	Up hillside of the BP Highway, about 1 km from the Golmithumka to the Bella village	Psammitic schist/ Kulekhani Formation	Two-set deformation, crenulated structures; Heterogeneous distribution of recrystallized and deformed quartz and mica; Presence of cross–cut of biotite and muscovite (Fig. 6)	Absent	Low quartz	Moderately	Absent	+Illite,1M
Kv11	Right bank of the Okhar Khola; about 100 m upstream from the suspension bridge, way to Baluwa	Micaceous quartzite/ Chisapani Quartzite	One set of strong foliation seen by preferred orientation of muscovite grains (Fig. 7).	Absent	Low quartz	Highly	V. low reactive	-
Kv12	Right bank of the Bhotekate Khola, below the Charuwa village	Macaceous quartzite/ Kalitar Formation	One set of strong foliation defined by mica minerals. Quartz grains are recrystallized and deformational laminae of mica are frequent (Fig. 8).	Absent	Low quartz	Highly	V. low reactive	-

*XRD analysis, +Illite, 1M is a structural polytype in which stacking pattern is linear and unidirectional.

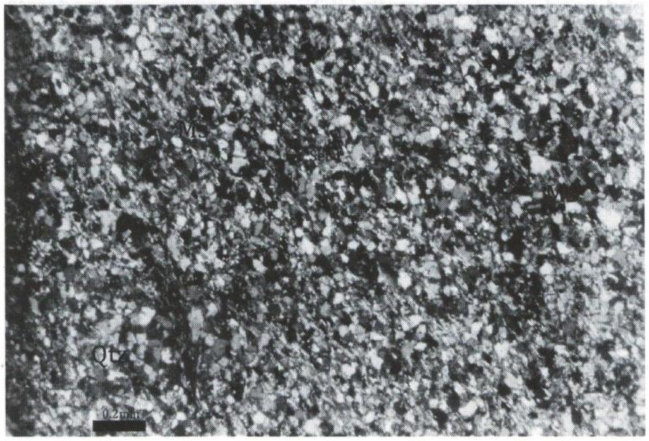

Fig. 3: Photomicrograph of metasiltstone showing the equigranular quartz grains and microlaminae (Sample no. KV9). Qtz=quartz, ser=sericite, Ms=muscovite.

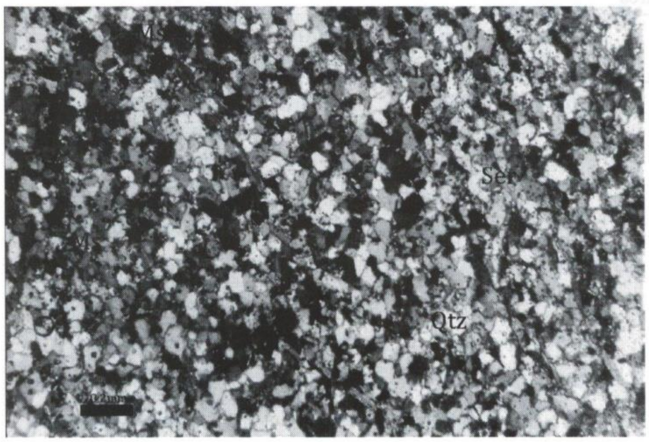

Fig. 4: Photomicrograph of metasandstone showing the equigranular quartz grains and microlaminae (Sample no. KV7). Qtz=quartz, ser=sericite, Ms=muscovite.

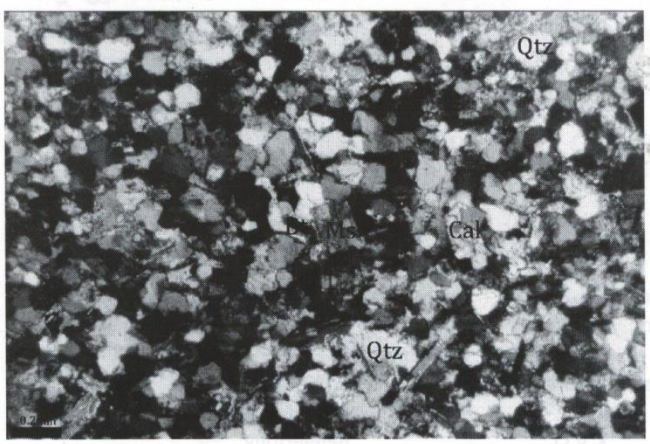

Fig. 5: Photomicrograph of psammitic schist showing the granoblastic texture, anhedral predominant quartz and slightly oriented mica (Sample no. KV3). Qtz=quartz, Cal=calcite, Bt=biotite, Ms=muscovite.

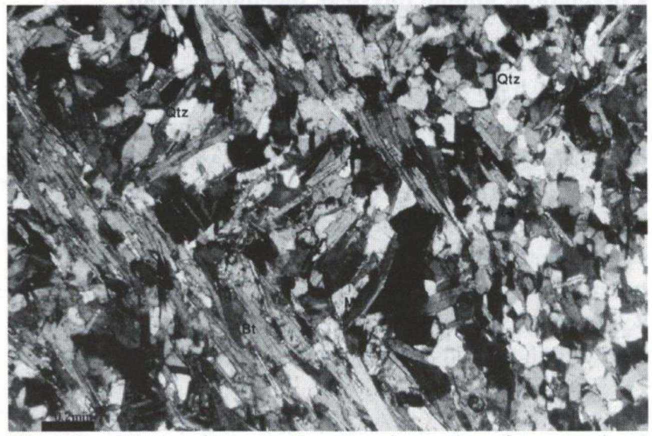

Fig. 6: Photomicrograph showing the fine grained recrystallized quartz, orientation of mica and crenulation cleavage (Sample no. KV1). Qtz=quartz, Fls=feldspar, Bt=biotite, Ms=muscovite.

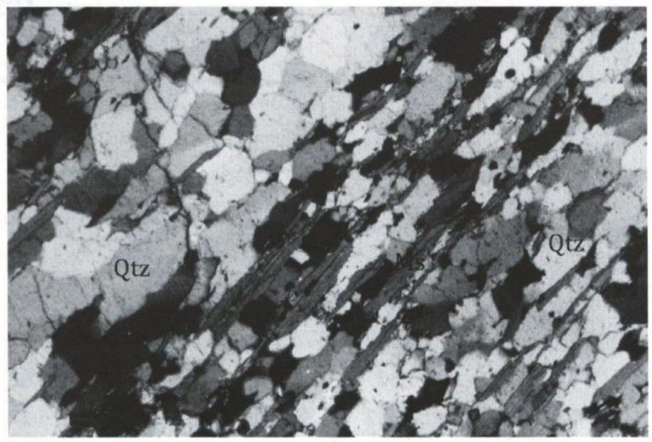

Fig. 7: Photomicrograph of quartzite showing the coarse grained, fractured, undulose extinction, on quartz and preferred orientation of muscovite (Sample no. KV11). Qtz=quartz, Ms=muscovite.

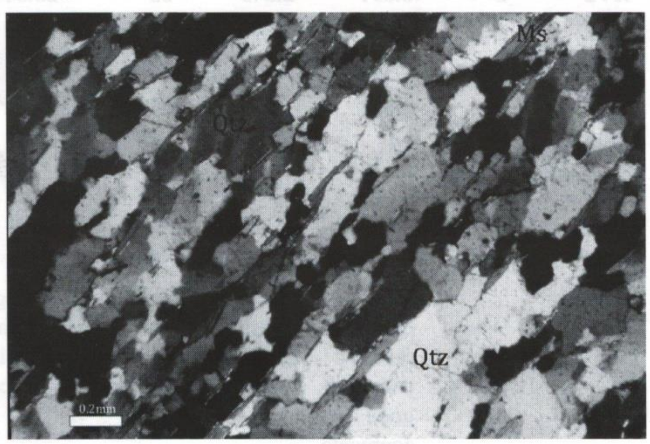

Fig. 8: Photomicrograph showing the undulose extinction, suture contact, fractured and coarsely crystalline quartz and orientation of mica grains (Sample no. KV12). Qtz=quartz, Ms=muscovite.

Correlations among physical, mechanical and petrographical parameters

When all the thirteen samples were correlated for each of individual parameters, only the relationships between ACV and AIV, UCS and ACV, Dry density and ACV and Dry Density and AIV were found to be of moderate degree of correlation. Therefore, attempt has been made to correlate and regress among the parameters for two distinct rock types: (a) quartzite/metasandstone/metasiltstone and (b) schist (Figs. 9 and 10). Considering the correlations in quartzite/metasandstone/metasiltstone, ACV has negative and good correlation with UCS, and positive and moderate correlation with AIV and dry density (Fig. 9). AIV is better explained by ACV compared to the other parameters, suggesting that whenever the aggregate crushing value increases in quartzite/meta-sandstone/meta-siltstone, the aggregate impact value also tends to increase. In schist, there are good and negative correlations between UCS and ACV and between dry density and ACV. ACV explains moderately the AIV and shows positive correlation. The mineralogical components such as quartz and feldspars (Qtz+Fls) also explain SSSV with good positive correlation (Fig. 10).

Table 7: Rock properties of the study samples compared with existing standard values and evaluation for concrete aggregate.

Sample no.		Properties							Evaluation
		WAV (%)	DD (%)	ACV (%)	AIV (%)	SSSV (%)	MBAV (%)	ASR/ deleterious	
KV9	D	0.739	2.591	35.4	20.76	16.66	0.83	No/little	Chemically unsound, mechanically satisfactory
KV8	A	0.450	2.658	24.83	17.12	7.93	0.67	No	Good for aggregate
KV7	A	0.586	2.525	22.73	15.01	10.71	0.50	No/little	Good for aggregate
KV6	A	0.902	2.308	21	12.49	10.44	0.67	No	Good for aggregate
KV10	A	1.189	2.483	21.4	15.55	13.28	0.67	No	Chemically fair
KV5	C	0.327	2.743	19.56	11.02	10.26	0.50	No/little	Good for aggregate
KV4	B	0.302	2.673	22	16.12	9.91	0.67	No	Good for aggregate
KV3	C	2.392	2.359	30.5	23.67	11.02	0.50	No/little	Mechanically satisfactory
KV13	C	0.401	2.735	23.16	23.84	5.95	0.50	No	Good for aggregate
KV2	C	0.691	2.645	23	23.31	9.97	0.67	No/illite	Good for aggregate
KV1	C	0.488	2.644	22.16	19.29	9.97	0.67	No/little	Good for aggregate
KV11	B	0.405	2.569	24.66	22.43	12.08	0.50	No	Chemically fair
KV12	B	0.357	2.599	25.66	22.64	12.55	0.50	No	Chemically fair
Existing standards	ASTM	<3	2 - 3	<30	<30	<12	<1 %		
	BS	<1							
	NS	<4	2.622	<45	<45	<12		<5	
Remarks		Low effective porosity and act as good for aggregate	Average density for aggregate	Sound for concrete aggregate	Strong and satisfactory to resist impact load	Resist to chemical weathering except KV9, KV11, KV12, KV10	Negligible amount of swelling clay	Absence of alkali-silica reactivity and little presence of deleterious materials	

A, B, C and D are rock categories

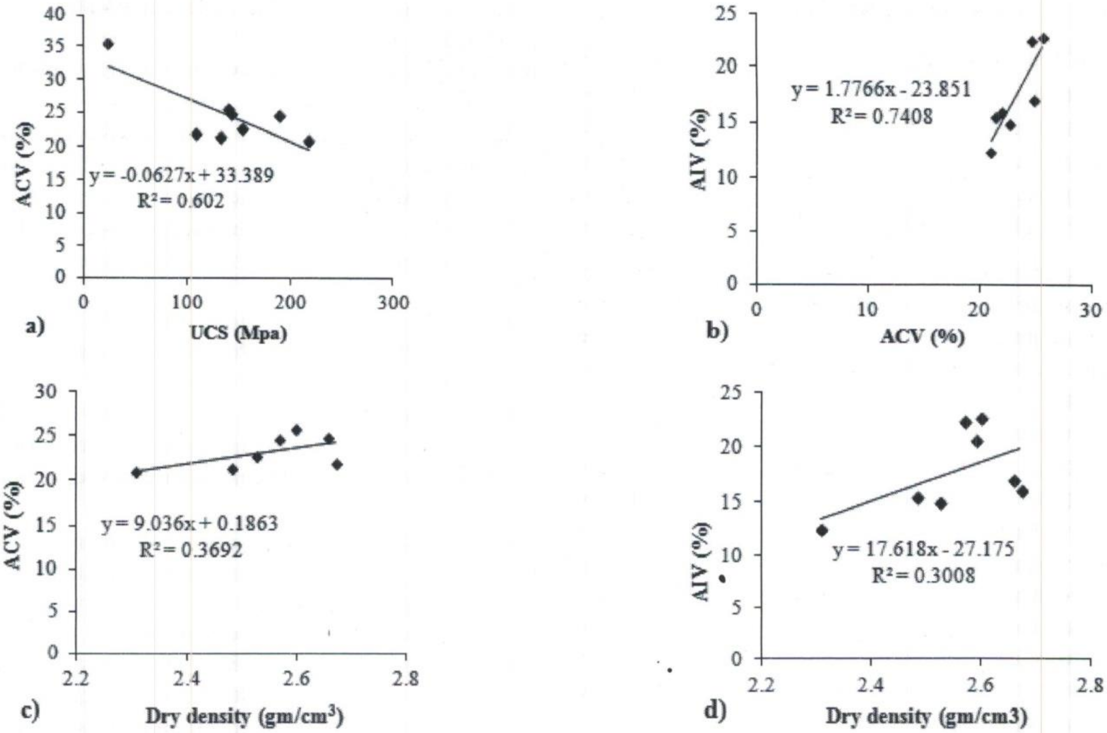

Fig. 9: Relationship between different parameters in metasandstone/metasiltstone/quartzite. a) UCS and ACV b) ACV and AIV c) dry density and ACV and d) dry density and AIV.

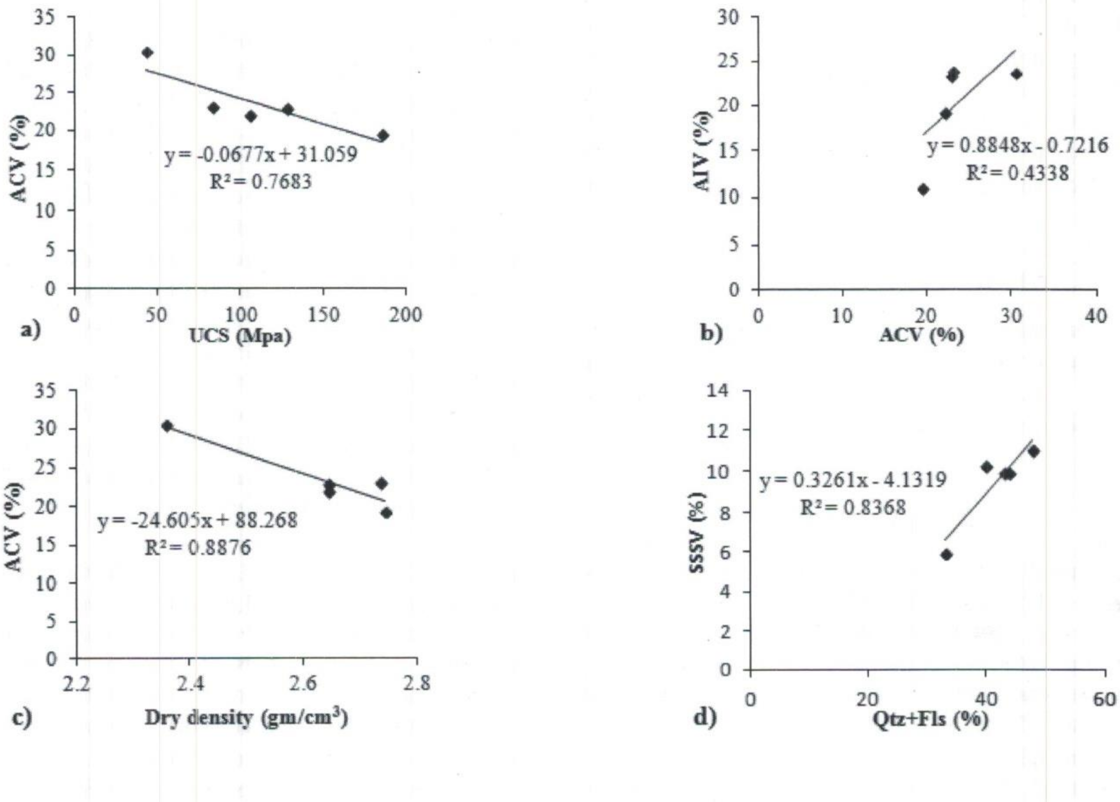

Fig. 10: Relationship between different parameters in psammitic schist. a) UCS and ACV b) ACV and AIV, c) dry density and ACV and d) quartz+feldspar and SSSV.

CONCLUSIONS

1. The Kavre area comprises the Lesser Himalayan rocks, which consist mainly of three to four major joint sets, the rock mass is nearly fresh, indurated and strong enough showing that the aggregates have a good stiffness for using as concrete aggregate. The rock masses are classified into fair to good rock class according to rock mass rating system.

2. The Lesser Himalayan rocks from the Kavre area meet the ASTM standard and Nepal Standard and are acceptable for concrete aggregate. However, except for metasiltstone which cannot be used in pavement as it shows high ACV, SSSV and clay. The psammitic schists are less prioritized for the aggregate due to high mica content. The best selection among the rock type for the concrete aggregate is metasandstones of the Tistung Formation and quartzite of the Markhu Formation. Second selection is quartzites of the Kalitar Formation, Chisapani Quartzite and Markhu Formation. Such rock types have been widely distributed around the peripheral regions of the Kavre area along the Arniko Highway and BP Highway. Therefore, these rocks can be the better source for concrete aggregate which can be used on increasing infrastructure development.

3. ACV of quartzite/metasandstone/metasiltstone has positive and moderate correlation with AIV and dry density, but negative and good correlation with UCS. AIV is better explained by ACV compared to the other parameters. In case of schists, there are good and negative correlations between ACV and UCS, and between ACV and dry density. ACV explains moderately the AIV and shows positive correlation. The mineralogical components such as quartz and feldspars (Qtz+Fls) also explain SSSV with good positive correlation.

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