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Rock Aggregate Potential of Limestone Units in the Khyber Formation, Pakistan

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Abstract: The Precambrian carbonates of the Khyber Formation are evaluated in terms of their petrographic, geochemical and physico-mechanical properties for assessing their suitability as an aggregate source both in asphalt and concrete works. The Khyber Formation is extensively exposed in the eastern and central parts of the district Khyber, Khyber Pakhtunkhwa. The limestone units of the Khyber Formation dominantly comprise calcite ($CaCO_3$;94-98%) with minor to trace concentration of dolomite, undeformed quartz and ores. The limestone of the Khyber Formation is classified as Algal laminated micritic mudstone. It is light to dark-grey, hard, compact, and thin to medium bedded and at places thick-bedded. The algal stromatolites and laminations are common. The stylolites, calcite-filled veins and neomorphism are the common diagenetic modifications in these carbonates. The limestone of the Khyber Formation is composed of 54.72-58.4 wt. % CaO_3, 0.5-0.9 wt. % MgO and based on a 0.02-0.22 wt. % combined values of K_2O and Na_2O, and it is classified as low to high alkali limestone. Massive outcrops of dolomitized-limestone have also been identified sporadically along the exposed outcrops of the Khyber Formation e.g. in Besai area and along Khyber Pass. The petrographic and chemical investigations show that the limestone units of the Khyber Formation are innocuous in terms of Alkali Silica Reactivity (ASR) and Alkali Carbonate Reactivity (ACR). However, the dolomitized horizons must be avoided, owing to its ACR potential while selecting a quarry site for aggregate extraction. The physical properties of the limestone units of the Khyber Formation as an aggregate material (i.e. soundness, water absorption, Los Angles abrasion, specific gravity and unconfined compressive strength) are in accordance with the ASTM standards. The petrographic, geochemical and geotechnical details of the limestone units in Khyber Formation approve their suitability as an aggregate source in both concrete and asphalt construction works.

Keywords: Precambrian limestone, petrography, geochemistry, physicomechnical tests, aggregate.

Introduction

The importance of locating appropriate aggregate sources near the construction sites can't be denied, as it affects the strength, durability and cost of the civil structures. The aggregate, if it contains certain constituents, may react with the alkali hydroxides in the cement and may cause considerable expansion over time. This expansion may considerably reduce the durability and strength of the civil structure. The reactions involving alkali in cement and deleterious components in aggregate is of two types i.e. 1) Alkali-silica reaction (ASR) and 2) Alkali-carbonate reaction (ACR, also known as alkali-carbonate rock reaction). Among these two, the ASR is more common as aggregates containing ASR prone constituents i.e. reactive silica minerals are naturally common (Farny, 1996).

The suitability of an aggregate source in construction works can be better evaluated through its petrographic, geochemical and physicochemical investigations (Berube and Fournier, 1993). This study thus uses these techniques to evaluate the aggregate potential of the carbonates units in the Khyber Formation exposed in the study area.

Geology of Study Area

Tectonically, the Khyber area lies at the junction of two major tectonic zones of northern Pakistan; (i) Northwest Himalayan fold and thrust belt (ii) Himalayan Crystalline Nappe and Thrust Belt.

The Khyber Ranges are a part of the Khyber Lower Hazara metasedimentary fold and thrust belt (Fig. 1). This thrust belt lies towards the north of Khairabad-Panjal Thrust and extends eastward from Khyber Pass region to Garhi Habibullah. The Khyber-Hazara metasedimentary Belt is largely composed of Precambrian to early Mesozoic sediments. The Precambrian sequence is mainly comprised of slates and phylites with subordinate quartzite and marble, which crop out in the southern part of the belt. The Khyber-Hazara metasedimentary fold and thrust belt have been intruded by mafic dykes, sills and granitic rocks of which the extensive Ambela pluton and Warsak granite are conspicuous. These intrusive rocks range in age from Late Paleozoic to Early Mesozoic. This metasedimentary belt is characterized by tight, asymmetrical or isoclinal folds imbricated by several thrust faults (Shah et al., 1971; Pogue et al., 1992).

A controversy exists among the researchers regarding the stratigraphic set-up and nomenclature of the area owing to the complex structural setup of the region and non-adequate age control over the rock units (Shah, 2009). The work of Shah (1969 and 1980) and Khan et al. (1989) has been summarized in Table 1.

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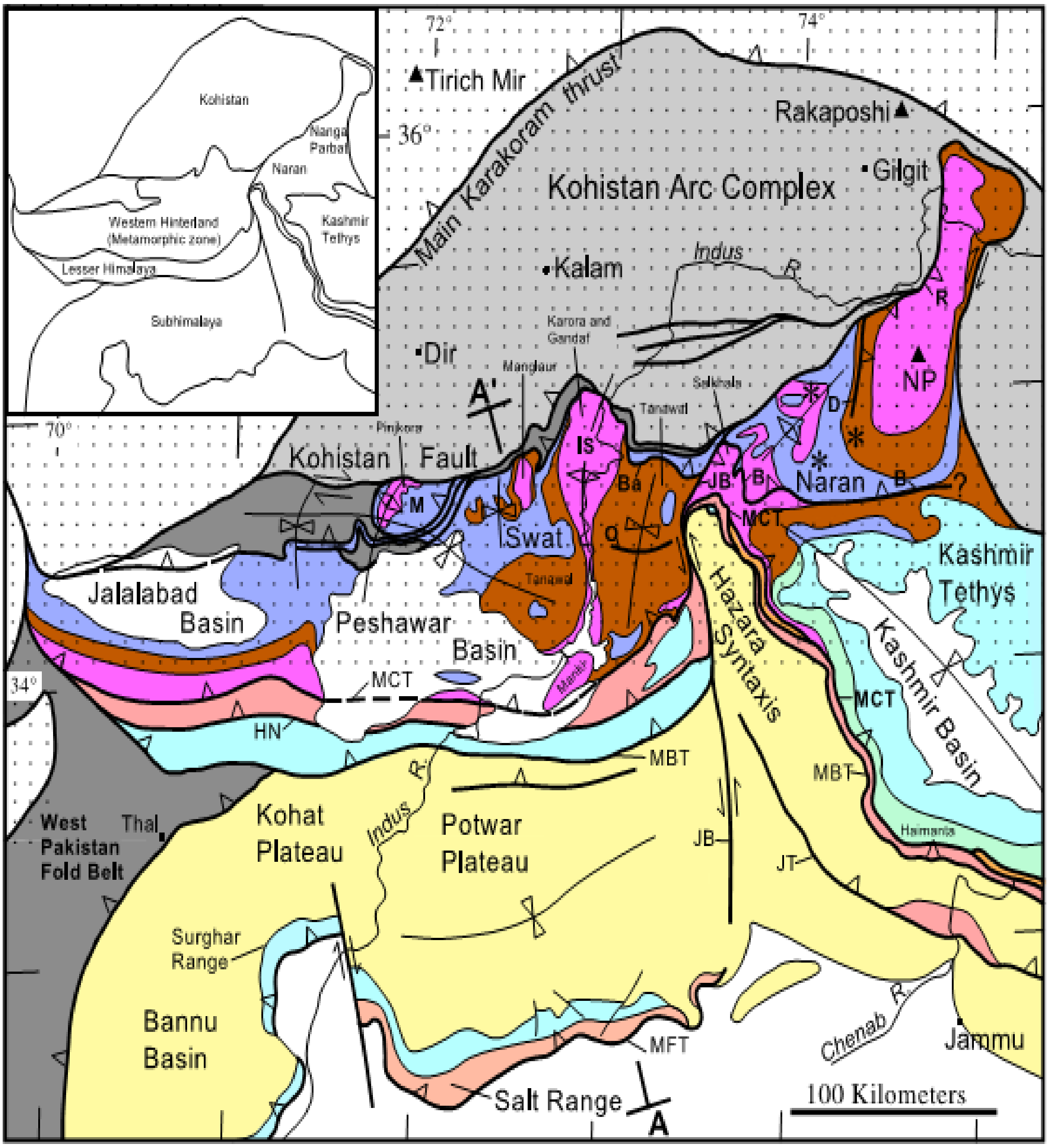

Fig. 1 Regional tectonic map of North Pakistan showing geological setting of the study area. MCT- Main Central Thrust; MBT- Main Boundry Thr MFT- Main Frontal Thrust; JB- Jhelum Balakot Fault; JT- Jammu Thrust; HN- Hissartang-Cherat-Nathia Gali Thrust; IS- Indus Syntaxis; (O- Oghi Fault; Ba- Banna Fault; b- Batal Fault; R- Raikot Fault; NP- Nanga Parbat; M- Malakand Slice (After, Dipietro and Pogue, 2004).

Constituting an important member of the area, the Precambrian Khyber limestone (Khan et al., 1989) in the Khyber Pass section is dominantly composed of thin to thick bedded and at places massive limestone (Fig. 2A). The limestone is light gray, hard, compact and is dolomitic at places. Algal stromatolites are common in the Khyber limestone (Fig. 2B).

Materials and Methods

The Khyber limestone was sampled from Sur Qamar Quarry near the Khyber Pass Highway in the east Khyber Range (Figs. 1, 2A). An integrated petrographic, geochemical and geotechnical approach was adopted to assess the aggregate potential of these carbonates. About 10 representative thin sections were prepared from the sample of the Khyber limestone for detailed petrographic analysis. To appraise the chemical suitability of these carbonates, various oxides e.g. SiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, Na_2O and K_2O were determined using Energy Dispersive X-ray spectroscopy (EDXA). The standard aggregate physico-mechanical tests including Unconfined Compressive Strength, Los Angles Abrasion Test, Soundness Test (using saturated solution of Magnesium sulphate) etc. on the aggregate samples of these carbonates were performed.

Results and Discussion

Petrography

The limestone of the Khyber Formation in hand specimen, is light grey to dark-grey on fresh and yellowish-greyish to yellowish on weathered surface. It is fine to medium-grained, fractured, thin to medium-bedded, hard, compact and is partially recrystallized (Fig. 2). In thin sections, the limestone is dominantly composed of micrite (94-98%), algal laminations (1-3%), neomorphic calcite (2-5%), uncommon dolomite (0.5-2%), rare quartz (0.5-1%), ores (0.5-1%) and clays (1-2%; along stylolites; Fig. 2). Stylolites, and cleaved coarse calcite grains occur in the limestone. The studied limestones can be classified as "Mudstone" according to Dunham (1962) classification scheme. The neomorphism, rare dolomitization, calcite filled veins and stylolites are the various diagenetic modifications that the Khyber Limestone has undergone (Fig. 2). The neomorphic calcite is composed of very fine, to coarse-grained anhedral spar at some places. The dolomite is mostly fine grained with rare typical rhombohedral grains. The quartz is commonly very fine grained and is generally undeformed. The clays typically occur along stylolites (Figure 2).

Geochemistry

The limestone is mainly dominantly composed of $CaCO_3$, which to certain extent may have been replaced (at places) by $MgCO_3$ during diagenesis. Most of the limestones are generally composed of pure $CaCO_3$ and have less than 5% impurities. The impurities in limestone determine its usage in various industries. The nature and mode of impurities in limestone also varies. The impurities may be syn or post depositional

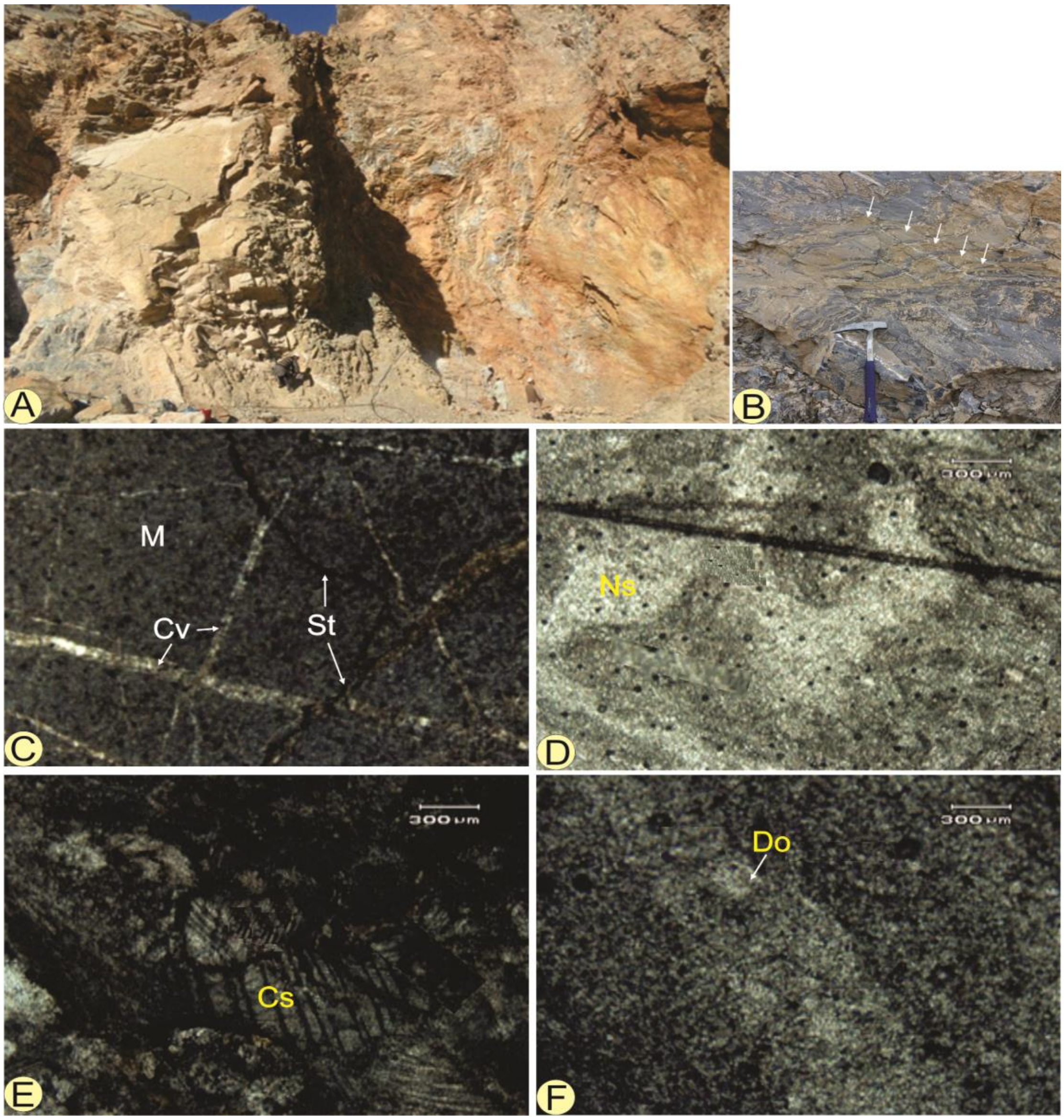

Fig. 2 A) Field photograph of the limestone in Khyber Formation exposed in Sur Qamar, Quarry; B) Field photograph of the algal lamination; C) Photomicrograph of the limestone showing micrite (M), calcite filled veins (Cv), stylolites (St); D) showing neomorphic calcite (Ns); E) Showing coa sparry calcite with well-developed cleavages (Cs); F) Dolomitization (Do) in the micritic limestone.

in origin. The high MgO content in a limestone unit indicates increase in its dolomite component and thus an increase in its ACR potential. The amount of silica (SiO_2) and Al_2O_3 in limestone is important, as it determines its appropriateness for use as aggregate in concrete works.

The limestone samples from Khyber Formation were subjected to EDX analysis to determine its chemical composition (Table 2). The analyzed limestone samples are high in CaO i.e. 54.66 to 58.85 and can be regarded as highly pure. The amount of SiO_2 in the studied limestone is very low and ranges from 1.34 to 1.81 %. The amount of MgO is also very low and ranges from 0.55 to 0.91%. The Al_2O_3, K_2O and Na_2O are present in trace amount in Khyber Formation limestone i.e. 0.48 to 0.69%, 0.04% to 0.08% and 0.16% to 0.28% respectively (Table 2). Since the limestone of the Khyber Formation is high in purity thus, it has a high average value (40.13%) of loss on ignition i.e. CO_2 content (Table 2).

Table 1. Stratigraphy of the Khyber area (after Shah et al., 1980; Khan et al., 1989).

Shah et al., (1980)	Khan et al., (1989)
Khyber limestone	Landikotal slates
Ali Masjid Formation	Khyber formation
Shagai limestone	Shagai formation
Landikotal formation	

Table 2. Major and minor oxides of the representative limestone samples from the Khyber Formation.

Oxide	Sample 1	Sample 2	Sample 3	Average
CaO	58.85	54.66	56.82	56.78
SiO_2	1.34	1.45	1.81	1.53
MgO	0.69	0.55	0.91	0.72
Al_2O_3	0.62	0.61	0.48	0.57
K_2O	0.04	0.07	0.08	0.06
Na_2O	0.16	0.18	0.28	0.21
LOI	38.3	42.48	39.62	40.13
Total	100	100	100	100

Engineering Properties

The intended use of a limestone deposit can be better assessed through the determination of its various physical and mechanical parameters. In case of a limestone deposit to be used as a construction aggregate source, the determination of its physical strength and durability is of prime importance (Harrison, 1993). For this purpose, the representative aggregate sample from the Khyber limestone was subjected to various standard aggregate tests including Los Angles Abrasion (ASTM C-131-03), soundness (ASTM C-88, 1999), unconfined compressive strength (ASTM D-2938, 2000), specific gravity and water absorption (ASTM C-127-88). The Los Angles Abrasion value for the limestone sample is 26.65 %, while the soundness value is c. 2.54 (mean) which is under the acceptable range for sub base, base, asphalt concrete and cement concrete work, as an aggregate with LA and soundness of less than 40% and 12% respectively is considered resistant to the process of weathering (Table 3). The unconfined compressive strength value ranges from 19.86-39.08 (Table 4). While specific gravity of the investigated limestone is 2.72, its water absorption is 0.68% (Table 3). Flakiness index test (BS 812 part 10; 1990) determines the total weight of aggregate that passes through opening of gauge. It is measured in percentage to the total weight of the sample. Flakiness index value demonstrates a range of 16.2 -19.0% which is well within standard limits (e.g., 45% for asphalt work). Elongation index test (BS 812 part 105, 1990) determines the total retained weight (%) of aggregate on the elongated gauge calculated to total sample weight. The crushed elongation index is usually 1.5 times the flakiness index. A range of 20.5% to 25.2% value is measured for the Khyber limestone, which shows their suitability for use with both the asphalt and cement-concrete.

Comparison with Other Limestone Deposits

The Paleocene-Eocene limestone deposits of Pakistan are extensively used as a prime source of lime in various industries like cement, paint, fertilizers, steel, glass etc. and as aggregate and dimension stone in construction industry, owing to their supreme quality limestone. A comparative account of various physical properties of the well-known limestone deposits of Pakistan and the limestone from Khyber Formation are summarized in Table 3. This comparison shows that the limestone units of the Khyber Limestone are appropriate for use in various industries and as an aggregate source (Tables 3-5) in the construction sector.

The limestone is one of the most abundant sedimentary rocks and is dominantly composed of calcium carbonate with trace amounts of silica, iron, aluminum, magnesium carbonate and clay. It is also one of the most widely used industrial rocks. The limestone units in the Khyber Formation exposed along the Khyber Pass is evaluated in terms of its textural, physical and chemical properties to assess its construction aggregate potential.

The investigated limestone is thin to medium-bedded, fine-grained, and dominantly composed of calcite (96-98%) in the form of micrite and spar. Rare quartz, carbonaceous material, clays along stylolites and dolomite also occur. The amount of quartz, clay and dolomite in rocks is important to determine their chemical reactivity and thus durability. The amount of quartz, clays and dolomite in the limestone from Khyber Formation is far below than their threshold reactivity percentage i.e. >5% deformed quartz for

Table 3. Geotechnical comparisons of different limestone formations with that of the Khyber Formation.

Limestone Unit	Texture	Specific gravity	Water absorption%	Loss Angles value %	UCS (Mpa)
Lakhra Limestone (Brohi et al, 2012)	Wacke-packstone	2.19-2.36	2.53-8.74	22.3	-
Margalla Hill Limestone (Khan, 2009)	Wacke-packstone	2.68-2.72	0.8	21.6	27.68 – 37.30
Kohat Limestone (Gohar, 1999)	Wacke-packstone	2.6-2.72	0.6	21.2	-
Lockhart Limestone (Khan, 2009)	Wacke-packstone	2.69	0.62	22.7	-
Khyber limestone (This Study)	Mudstone	2.72	0.68	26.6	19.86 – 38.06

Table 4. The sample details and calculations used for UCS determination.

Sample no.	Diameter (In)	Diameter (m)	Radius (m)	Length (In)	Length (m)	Area (m^2)	Applied load (Ton)	Applied load (KN)	UCS
1	1.73	0.044	0.0041	3.9	0.099	0.001541	3.1201	30.59	19.86
2	1.73	0.044	0.0041	3.9	0.099	0.001541	5.9812	58.64	38.06
3	1.73	0.044	0.0041	3.9	0.099	0.001541	6.1414	60.21	39.08
4	1.73	0.044	0.0041	3.9	0.099	0.001541	3.588	35.18	22.84

Table 5. Material grading based on UCS (after Bell, 2007).

Geological Society (Anon,1977)		IAEG* (Anon,1979)		ISRM** (Anon,1981)	
Description	UCS (MPa)	Description	UCS (MPa)	Description	UCS (MPa)
Very weak	<1.25	Weak	<15	Very low	<6
Weak	1.25-5.00	Moderately weak	15-50	Low	6-10
Moderately weak	5.00-15.50	Strong	50-120	Moderate	20-60
Moderately strong	12.50-50	Very strong	120-230	High	60-200
Very strong	100-200	Extremely strong	>230	Very high	>200
Strong	50-100				
Extremely strong	>200				

*International Association of Engineering Geologists

**International Society for Rock Mechanics

ASR (NRMCA, 1993) and 5 to 25% for ACR (Ozol, 2006). Thus, the analyzed limestone is not prone to both ASR and ACR. The petrographic results are also consistent with chemical analysis as depicted by the low concentration of SiO_2 i.e. 1.34-1.81 and MgO i.e. 0.55-0.91 in the analyzed samples.

The rock texture controls its physical strength. The mineralogically similar fine-grained rocks are generally stronger than their coarse-grained counterparts. Besides, an extended range in grain size gives higher strength and better resistance to fragmentation and wear, as compared to a more equigranular rock (Lindqvist et al., 2007). The above statement can be correlated with the UCS results of both types of cores i.e. fine grained and coarse. The UCS results for fine-grained cores are higher i.e. 39.08 as compared to coarse-grained cores i.e. 19.86 (Table 4).

Presence of discontinuities like cracks, cleavages, foliation and stratification in rocks reduces their effective strength. The mechanics of fracturing in rocks is strongly controlled by the presence of micro-cracks, which dramatically reduce strength of the rocks through stress concentration. Some cracks are intra-granular, and some are inter-granular (Lloyd and Knipe, 1992). The fractures at the outcrop scale and discontinuities at the microscopic scale are common in the investigated limestone. The microscopic scale discontinuities include stylolites, unfilled fractures and cleavages in the coarse calcite crystals. Presence of these discontinuities can substantially reduce the strength of these limestones e.g. the low UCS value (19.86 Mpa) for the coarse limestone can also be attributed to dense fractures in them.

Apart from petrography and geochemistry various ASTM standard aggregate tests were also performed on the aggregate samples of the limestone samples from the Khyber Formation. The Los Angles Abrasion value for the studied limestone is 26.6% which is within the permissible ASTM range i.e. 0-40%. This LA value is a bit higher as compared to other common aggregate sources like Kohat Limestone and Margalla Hill Limestone (Table 3). This increase can be attributed to comparatively thin bedded nature and high degree of fractures both at the outcrop and thin section scale in the investigated limestone.

The soundness value for the studied limestone is 2.54 %, which is within the permissible range of weight loss as suggested by the ASTM i.e. 0-12%. The soundness value is almost like that of Kohat and Margalla Hill limestone (Table 3). Thus, the limestone from Khyber Formation is chemically stable and is suitable for use in concrete structures without affecting its strength through volume loss. The specific gravity is a measure of rock density which determines the rock strength. Greater the specific gravity, the greater is the mutual binding of its constituents and hence greater the force required to break them apart. It is also interrelated to water absorption, the greater the specific gravity of a rock, the lower its water absorption and hence porosity. Rocks having specific gravity >2.55 are considered suitable for heavy construction works (Blyth and de Frietas, 1974). The specific gravity of the under-study rock is in permissible range with a value of 2.72. An indirect relationship does exist between water absorption, weathering and rock strength. Rocks with low water absorption values have high strength values and high resistance to weathering, showing more resistance to frost action and chemical weathering processes (Blyth and de Freitas, 1974). Thus, the water absorption is a useful physical property in evaluating the durability of different rocks as building materials (Shakoor and Bonelli, 1991). The measured water absorption value for the studied limestone is 0.68%, which is well below the permissible limit for its use as dimension stone and engineering material i.e. <1% (Akroyd, 1962; Blyth and de Freitas, 1974).

The UCS determines failure of a cylindrical rock core specimen in response to compressive stress in one dimension. The UCS values for the representative four samples of the studied limestone are 19.86 Mpa, 38.06 Mpa, 39.08 Mpa, 22.84 Mpa respectively (Table 5). All these samples can be categorized as moderately strong according to Anon, (1977), moderately weak according to Anon, 1979 and of moderate strength according to Anon, 1981 (Table, 5). The drastic difference of UCS values for Sample 1 and 4 (comparatively low values) and Samples 2 and 3 (relatively high values) can be attributed to comparatively large grain size and fractures abundance in sample 1 and 4 cores (Table, 4).

Conclusion

The limestone units in Khyber Formation, exposed along Khyber Pass in the Khyber Ranges are evaluated in terms of their petrographic, geochemical and physico-mechanical characters to evaluate their potential as an alternative aggregate source in construction works.

The limestone of Khyber Formation can be classified as mudstone and is dominantly composed of micrite (94-98%) with insignificant amount of dolomite (0.5-2%), quartz (0.5-1%), insoluble clays (1-2%) along stylolites and ores (0.5-1%). These limestones are also low in SiO_2 (1.34-1.81%) and MgO (0.55-0.91%) contents. Thus, both petrographic and geochemical data suggest that the limestone of Khyber Formation is not prone to ASR and ACR associated expansions.

The values of various standard aggregate tests for the studied limestone like Los Angles Abrasion (26.6%), soundness (2.54%), specific gravity (2.72), water absorption (0.68%), flakiness (16.2 -19.0%) and elongation (20.5% to 25.2%) are within the permissible ranges of standard specifications for normal aggregate used in concrete and asphalt.

The Unconfined Compressive Strength (UCS) values (19.86 – 38.06 Mpa) suggest these rocks to be moderately strong due to their highly fractured nature. This limits its use in high performance projects. However proper preventive and reinforcement measures may be effective in using it in heavy projects as well.

The comparison of Khyber limestone with other limestone units of Pakistan adds it to the list of limestone deposits which can be used in construction sector successfully.

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References

Akroyd, T. N. W. (1962). Concrete: properties and manufacture, First Edition, Pergamon Press, Inc., New York.

Anon, (1977). The description of rock masses for engineering purposes. Engineering group working party report, *Quaterly Journal of Engineering Geology*, **10**, 43-52.

Anon, (1979). Classification of rocks and soil for engineering geological mapping, part-1 rock and soil materials. *Bull.Int. Assoc. Eng. Geol*., **19**, 364-371.

Anon, (1981). Basic geotechnical description of rock masses. International society of rock mechanics commission on the classification of rocks and rock masses. *Int. J. Rock. Mech. Min. Sci*., **18**, 85-110.

ASTM C-88-1999. Standard test method for soundness of aggregates by use of sodium sulphate or magnesium sulphate, *American Society for Testing and Materials*, Philadelphia, Pa. USA, 1-5.

ASTM C-127-1988. Standard test method for density, relative density (specific gravity), and absorption of coarse aggregate, *American Society for Testing and Materials*, Philadelphia, Pa. USA, 77-82.

ASTM C-131-2003, Standard test method for resistance to degradation of small-Size coarse aggregate by abrasion and impact in the los angles machine. *American Society for Testing and Materials*, Philadelphia, Pa. USA, 1-4.

ASTM D-2938-2000, Standard test method for unconfined compressive strength of intact rock core specimens. *American Society for Testing and Materials*, Philadelphia, Pa. USA, 1-3.

Blyth, H. G. F., Freitas de, A. M. H. (1974). Geology of Engineers, ELBS and Edward Arnold, London, UK, 514 pages.

Bell, G. F. (2007). Engineering Geology, 2nd Edition. Butterworth-Heinemann: an imprint of Elsevier Ltd, United Kingdom, 293 pages.

Berube, M.A., Fournier, B. (1993). Canadian experience with testing for alkali aggregate reactivity in concrete. cement and concrete composites, **15**, 27-47.

Brohi, A., Solangi, S. A., Bablani, H. S., Agheem, H., Sahito, M. H. G. (2012). Geological and stratigraphic studies of dimensional and cut stone deposits around Khanu Brohi and Khadhar areas, Distt Jamshoro, Sindh, Pakistan. *Sindh Univ. Res J*., **44** (4), 581-586.

BS, (1990). Methods for determination of particle shape. Flakiness index and methods for determination of particle shape. *Elongation index of coarse aggregate*, BS 812 Part 105.

DiPietro, J. A., Pogue, K. R. (2004). Tectonostratigraphic subdivisions of the Himalayas: A view from the west. *Tectonics*, **23** (TC5001), 1-20.

Dunham, R. J. (1962). Classification of carbonate rocks according to depositional texture, In Ham, W. E. (ed) Classification of carbonate rocks. American Association of Petroleum Geologists Memoir, 108-121.

Farny, J.A. (1996). Diagnosis and control of alkali aggregate reactions in concrete. Portland Cement Association, American Concrete Pavement Association, Skokie, Illinois.

Gohar, A. (1999). Concrete feasibility for the limestone of the Kohat Formation. MPhil. Thesis, NCE in Geology University of Peshawar, Peshawar, Khyber Pakhtunkhwa.

Harrison, D. J. (1993). Industrial minerals laboratory manual limestone, Technical report WG/92/29, Mineralogy and Petrology series, British Geol. Surv, Keyworth Nottingham, U.K. NG12 5GG. 1-54.

Khan, K. M. 2009. Impacts of Margala Hills crushing plants on the environment, University of Engineering and Technology, Taxila, 45-52.

Khan, A., Aslam, M., Khan, R. N. (1989). Revised stratigraphy of the Paleozoic rocks, Khyber Agency, NWFP, Pakistan. Geol. Surv. Pakistan, **431**, 1–11.

Lindqvist, J. E., Akesson, U., Malaga, K. (2007). Microstructure and functional properties of rock materials. Mater. Charact., **58** (11-12), 1183–1188.

NRMCA. (1993). Guide Specifications for concrete subject to alkali-silica reactions, Mid-Atlantic Regional Technical Committee, (Available through NRMCA, Silver Spring, Maryland).

Ozol, M. A. (2006). Alkali-carbonate rock reaction, Significance of Tests and Properties of Concrete and concrete-making materials, ASTM STP 169D, edited by Lamond, J. F., Pielert, J. H., *American Society for Testing and Materials*, West Conshohocken, Pennsylvania, 410-424.

Pogue, K. R., DiPietro, J. A., Khan, S. R., Hughes, S. S., Dilles, J. H., Lawrence, R. D. (1992). Late Paleozoic rifting in northern Pakistan. *Tectonics*, **11**, 871-883.

Shah, S. M. I. (1969). Discovery of Paleozoic rocks in the Khyber Agency. Geonews, **1** (3), 31-34.

Shah, S. M. I., Siddiqui, R. A., Talent, J. A. (1980). Geology of the eastern Khyber Agency, N.W.F.P. Geol. Surv. Pakistan, Rec., **44**, 90 pages.

Shah, S. M. I. (2009). Stratigraphy of Pakistan. Geol. Surv. Pakistan, Mem., **22**, 381 pages.

Shakoor, A., Bonelli, R. E. (1991). Relationship between petrographic characteristics, engineering index properties, and mechanical properties of selected sandstones. *Bull. Int. Assoc. Eng. Geol*., **28** (1), 55-71.