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Petrographic, Mineralogical and Geo-mechanical Characteristics of Marble from Mohmand District, Pakistan: Implications for its Use in Construction Industry

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Abstract: This study aims to evaluate the suitability of marble deposits from Mohmand district for use in the construction industry. By employing an integrated approach that combines petrographic analysis, chemical assessments, and physico-mechanical testing, the study seeks to provide a comprehensive understanding of the marble's properties. Although, megascopically indistinguishable, the petrographic analysis identifies two varieties of carbonate rocks: Calcitic-marble and dolomitic-marble. The marble from the Sapari quarry is petrographically fine to medium grained and dominantly composed of subhedral to anhedral calcite (84-86%), dolomite (8-10%), quartz (6-8%) and trace amount of micrite and hence classified as calcitic-marble. Owing to less contents of dolomite and unstrained quartz, the calcitic-marble reveals very low reactive quartz and magnesium in the rock, hence no expansion if used in concrete with ordinary Portland cement (OPC). The petrographic and chemical investigations, therefore, endorse their innocuous non-reactive character for both alkali silica reactivity (ASR) and alkali carbonate reactivity (ACR). In contrast, the marble from Qaroon Ghundai quarry is mineralogically dolomitic and texturally fine grained, where subhedral to anhedral dolomite constitutes the major phase (97-98 %), while quartz and micrite occur as the minor phases. The results of the cube test of the dolomitic-marble demonstrate an expansion by 0.28 % which lies above threshold limit of 0.10% thus endorse the potential to initiate ACR. Hence, this marble is declared deleterious with respect to ACR. With the exception of soundness value, the dolomitic-marble produces relatively higher values for UCS, specific gravity, bulk density, LA and Schmidt hammer as compared to the calcitic-marble. The comparative analysis shows that the calcitic-marble is suitable for high alkali cement-concrete and asphalt-works as a coarse aggregate. Alternatively, the dolomitic-marble is only declared suitable for asphalt-based concrete due to its ACR potential, which endorses the significance of mineralogy and textures in controlling the physical and mechanical properties of rocks.

Keywords: Petrography, calcitic-marble, dolomitic-marble, construction industry, alkali carbonate reactivity.

Introduction

The rock aggregates are naturally occurring inert and durable construction materials that must hold the capability of strong bonding in cement-based as well as asphalt-based concrete (Langer, 2004). Engineering material like aggregate, dimension stones and quarry design are largely affected by the physico-mechanical and geochemical characteristics of rocks (Prentice, 1990). The petrographic analysis is one of the most important techniques, while investigating a rock for its suitability as an aggregate material as it addresses the presence and amount of deleterious material (Hammersley, 1989, Smith and Collins, 2001, Sajid et al., 2009; Berube, 1993; Anjum et al., 2018). The aggregate may contain such constituents which react with hydroxides of alkali occurring in the cement, thus forming such substances that reduce the strength and durability of the engineering structures by expansion due to water absorption. Two types of reactions are recognized on the basis of deleterious component reacting with the cement: i) alkali silica reaction (ASR) and ii) alkali-carbonate reaction (ACR). The ASR is more common engineering problem as naturally occurring aggregates generally consist of reactive silica, thus rendering ACR potential to the aggregate (Farney, 1996). Marble and limestone find applications in various fields but the most notable are those in the construction as construction material, as dimension stone and in cement industry (Mustafa et al., 2005). The marble of Mohmand district is also quarried for dimension stone and sizeable blocks can be extracted at places. However, more than 50% of the rock is wasted as left over material. The left-over material and areas, where deformed nature of rock does not allow blocks to be extracted for dimension stones, can be used as aggregate. The occurrence of suitable aggregate sources near the construction sites is of prime significance for a successful engineering project as it influences the sustainability, strength and finances of engineering structures. This study, therefore, uses the techniques of petrography, engineering properties and chemical alkali-carbonate reaction (ACR) tests for investigating the marble units as an aggregate source in the vicinity of under-construction Mohmand Dam Hydropower Project, Pakistan.

Geological Setting

The study area lies within the western hinterland zone at the north western edge of Indian plate. It is bounded to the south and north by Khairabad Thrust and Main Mantle Thrust Zone (MMTZ), respectively and to the east by Hazara Kashmir Syntaxis (HKS; Kazmi et al., 1997). Several phases of metamorphism have affected the western hinterland zone since collision with the Kohistan Island Arc (Coward et al., 1986; Rex and Khan, 1986). Dominantly the area is occupied by EW trending macroscopic structures which are believed to have formed as a result of NS shortening between Kohistan Island Arc and Indian plate (Dipietro et al., 2008). The northern and north western segments of western hinterland zone are composed of Precambrian to early Mesozoic metasediments. The Cambrian to lower Permian coarse grained granites and granitic gneisses cross cut the schistose rocks of Precambrian age. Metasediments of Permian to late Mesozoic age, belonging to Alpurai group, are unconformably overlying the older rocks. The Alpurai group sediments are intruded by the un-metamorphosed Cenozoic Malakand granite. In study area the Alpurai group sediments are emplaced onto the south over the Peshawar basin Quaternary alluvium, to the west by the undifferentiated upper Proterozoic to Mesozoic rocks of the Khyber and Mohmand districts, and to the west and north by mafic ultramafic ophiolite sequence of the Indus suture zone MMT (Dipietro et al., 2008) (Fig. 1).

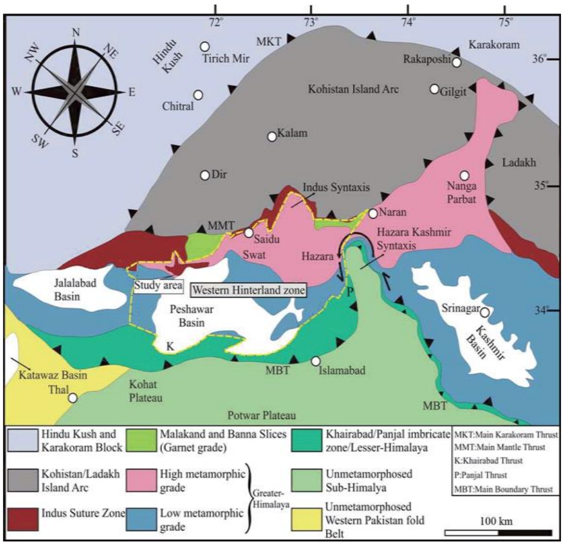

Fig.1 Tectonic map of Northern Pakistan. Small rectangle shows location of sampling area (DiPietro et al., 2008).

Materials and Methods

A total of five representative chip-samples and one bulk-sample were collected from the Sapari (34°20'42.74"N; 71°33'40.17"E) and Qaroon Ghundai (34°18'38.56"N; 71°40'22.67"E) quarries belonging to Mesozoic rock units in the vicinity of Mohmand Dam Hydropower Project (MDHP). An integrated approach is adopted by employing petrographic, chemical and geotechnical techniques to assess the aggregate potential of the marbles under study. A total of six petrographic sections were cut from each quarry at the rock cutting laboratory and thin sections were studied in detail under the petrographic microscope. All the minerals were identified based on the optical properties and photographed. Average modal mineralogy was calculated for all the thin sections using method of visual estimation through several views. The samples were pulverized and powdered to determine their mineralogical composition by X-Ray Diffraction (XRD).

The reaction between certain minerals within the aggregates such as dolomite and strained-quartz and the alkali metals like Na and K within the ordinary Portland cement is known as Alkali aggregate reaction (AAR; Smith, 2001). The AAR can occur in two forms i.e., ASR and ACR (Hewlett, 2006). Marbles may have deleterious components such as amorphous or deformed silica which can cause ASR in the concrete (Smith and Collis, 1996; Lorenze, 2001). Aggregates from dolostone or dolomitic marble can cause ACR in cement-based concrete, although such reactions are less common than ASR. The ASR (ASTM C 289-02, 2001) and ACR tests (ASTM C 586-05, 2006) were conducted at geochemical laboratory. The standard aggregate physico-mechanical tests including Unconfined Compressive Strength, Los Angles Abrasion Test, Soundness Test (using saturated solution of sodium sulphate) on the aggregate samples of these marbles were carried out at the Material Testing Laboratories. The Schmidt hammer test was performed in the field at outcrop level.

Results and Discussion

Petrography, XRD and AAR Analysis

Petrographic studies play a significant role in the identification of deleterious components in an aggregate because such constituents can react with the alkalis occurring in the cement and thus deteriorate the concrete structures (Printice, 1990; Swamy, 1992). Despite their macroscopic similarities, the petrographic investigation distinguishes two types of marbles (Fig. 2); calcitic-marble (Sapari quarry) and dolomitic marble (Qaroon Ghundai quarry). Petrographically, the greyish calcitic-marble (Fig. 2A) is fine grained, equigranular and composed of subhedral to anhedral grains (Fig. 2B-C). The samples are high in calcite (84-86%) followed by dolomite (8-10%), quartz (6-8%) with minor to trace concentration of micrite (Fig. 2A, B). This variety contains 6-8% of fine grained and undeformed quartz which does not cause alkali-silica reaction (ASR) in OPC-based concrete. Additionally, the calcitic-marble contains 8-10% dolomite. It is generally believed that dolomitic-marble or dolostone comprising 40-90% dolomite and 5-25% clays induce deleterious swelling, if used with OPC in concrete structure and thus cause ACR (Farny, 2007).

In the studied calcitic-marble, the content of dolomite varies between 8-10%. The concentration of dolomite is therefore, lower than threshold values allowed for ACR in cement-concrete and hence declared innocuous. Due to presence of abundant calcite minerals, the calcitic-marble is classified as innocuous (Fig. 2C, D). The dolomitic-marble on the other hand, contains 97-98% dolomite and minor to trace amount of unstrained quartz, and micrite. It contains subhedral to anhedral grains and is fine grained. The dolomitic-marble does not initiate ASR as the silica content in these marbles is not reactive enough to cause such issues. However, owing to higher dolomite concentartion, this variety is susceptible to ACR and hence classified as deleterious. The XRD analysis, while supporting petrographic analysis, shows significant presence of calcite along with a minor amount of quartz in marble from Sapari quarry defining it as calcitic (Fig. 3A). In contrast, marble from Qaroon Ghundai quarry is composed dominantly of dolomite with minor to trace amount of quartz (Fig. 3B).

The results of petrographic analysis for both the calcitic and dolomitic-marble are endorsed by employing the chemical techniques of ASR (ASTM C 295) and ACR (ASTM C 586-05, 2006). The alkali-silica reactivity test was conducted to evaluate the potential reactivity of siliceous components (deformed quartz) in the aggregate with alkalis (K and Na) occurring in the Portland cement through cubes prepared for both the marble types. The calcitic-marble shows no reaction due to lower values of strained quartz. Likewise, the dolomitic-marble did not show any reaction with ordinary Portland cement (OPC) due to lack of deformed quartz. The values of ASR are plotted for calcitic and dolomitic (Fig. 4). Moreover, ACR test is conducted to examine the expansion behavior of the rock-cubes of both calcitic and dolomitic-marbles. The expansion of a rock dominantly depends on the amounts of dolomite and clays occurring in it. Due to occurrence of lower concentration of dolomite and lack of clays in calcitic-marble, it reveals no expansion. However, cubes of dolomitic-marble which contain 96-97% dolomite demonstrate 0.28% expansion, a value higher than the specified limit of 0.10% set by ASTM standard (C-586, 2006). This study therefore, suggests that deleterious minerals in calcitic-marble variety are lower than threshold values to initiate ASR and ACR, while dolomitic-marble shows higher values than threshold values. Thus, the analyzed dolomitic-marble is prone to ACR in ordinary Portland cement-based concrete. It is therefore, concluded that the aggregate of calcitic-marble is innocuous with respect to both ASR and ACR, and hence suitable as aggregate material for the engineering projects. In contrast, the dolomitic-marble is deleterious in terms of ACR, and can only be used as aggregate in asphalt works (Fig. 4). As shown in the Figure 4, a potential deleterious category is demonstrated, if the test results plot to right of the boundary line, whereas the aggregate is classified as innocuous, if its results lie to the left side of the boundary line.

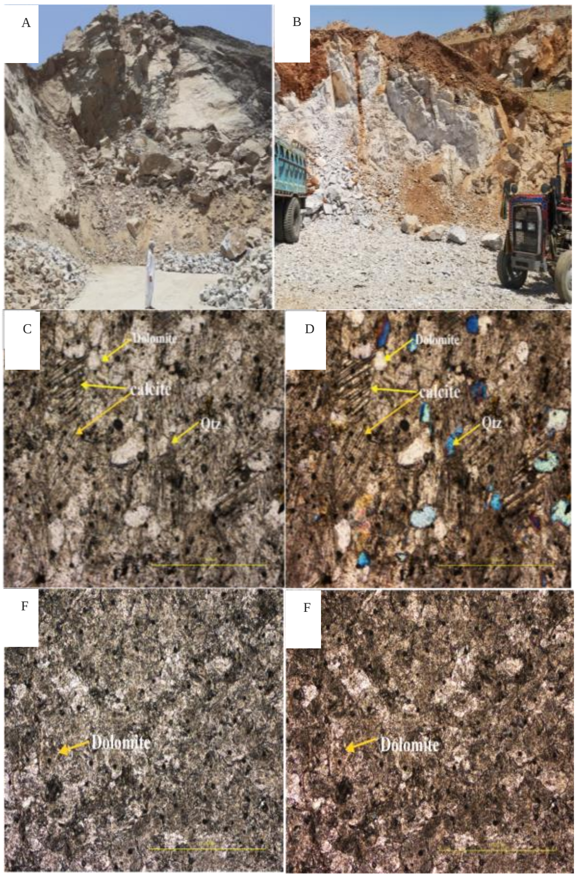

Fig. 2. Field photographs of the sampled marble quarries (A, B): Sapari quarry (A; calcitic marble Qaroon Ghundai quarry (B; dolomitic marble,. Microphotographs (C, E in PPL and D, F in XPL); calcitic-marble (C, E), showing calcite with well-developed clevages, dolomite and quartz; dolomitic-marble showing dolomite (E, F).

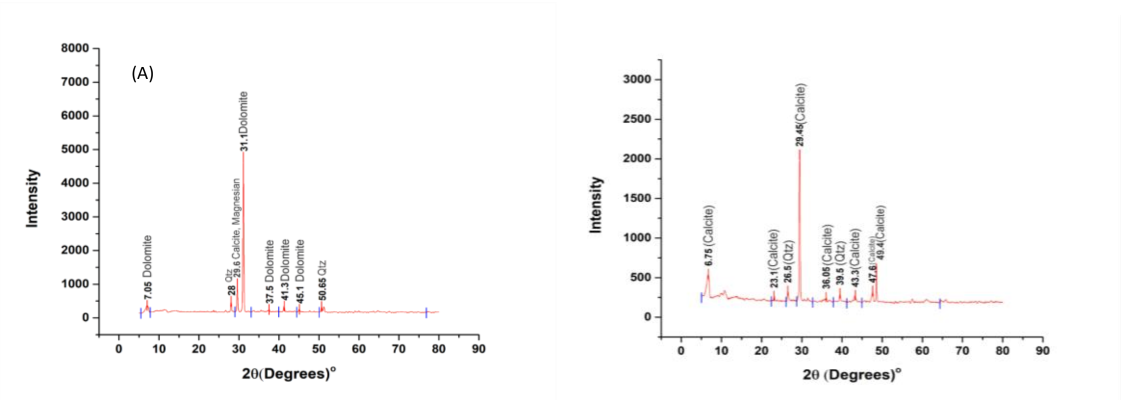

Fig. 3. XRD peaks of calcitic-marble (A) and dolomitic-marble (B)

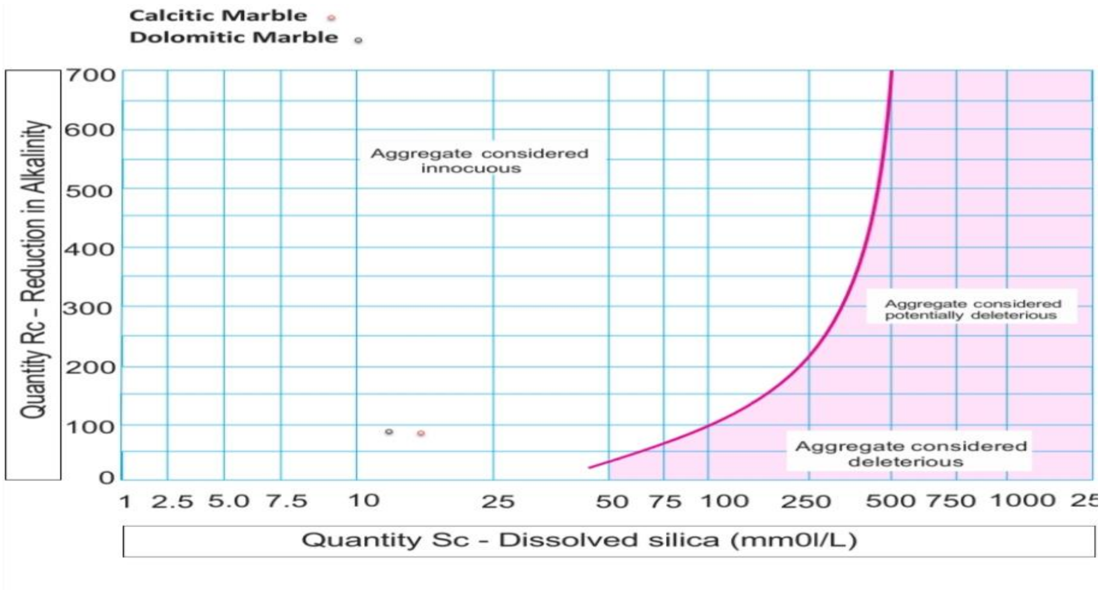

Fig. 4. The values Sc (dissolved silica) and Rc (reduction alkalinity) are plotted for calcitic and dolomitic-marble (Reproduced from IS: 2386 (Part VII 1964).

Table 1. Summary of test values for calcitic and dolomitic-marble samples against the acceptable range of ASTM.

Property	ASTM requirement	Sapari Quarry Marble				Qaroon Ghundai Marble			
UCS	ASTM >15MPa	42.32	31.90	36.39	48.10	74.13	66.25	81.83	76.89
Soundness	ASTM 0-12%.	2.5%				1.7%			
Water Absorption	ASTM <1%	0.57%				0.41%			
Specific Gravity	ASTM >2.55	2.732				2.846			
Bulk Density	ASTM ≥ 2.55 gm/cm^3	2.690				2.813			
L.A Abrasion	ASTM 0-40%.	34.7%				27.8%			
Schmidt Hammer	ASTM >30	41.83	40.33	-	-	44.33	43	-	-

Table 2. Grading of geological material on the basis of unconfined compressive strength (Shakoor et al., 1991).

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 strong	15-50	Low	6-10
Moderately weak	5.00-12.50	Strong	50-120	Moderate	20-60
Moderately strong	12.50-50	Very strong	120-230	High	60-200
Strong	50-100	Extremely strong	Over 230	Very high	Over 200
Very strong	100-200				
Extremely strong	Over 200				

* International Association for Engineering Geologists. **International Society for Rock Mechanics.

Physio-mechanical Properties

The intended use of a marble deposit can be better assessed through the determination of its various physical and mechanical tests. In case of a marble deposit to be used as construction aggregate source, determination of its physical strength and durability is of prime importance (Harrison, 1993). For this purpose, the rock samples from both the calcitic and dolomitic-marbles were subjected to various standard tests including unconfined compressive strength (ASTM, D 2938-95), soundness (ASTM D 2938-95, 2002), Los Angles abrasion (ASTM, 2003), Schmidt rebound hammer test (ASTM, C 805, BS, 1971), water absorption (ASTM C 127, 2001), bulk density (ASTM D 6683, 2019) and specific gravity (ASTM C 128, 2015). The UCS values for the samples from calcitic-marble are 31.90 MPa, 36.39 MPa, 42.32 MPa and 48.10 MPa, respectively, and can be categorized as moderately strong (Anon, 1977), while the UCS values for the dolomitic-marble samples are 74.13 MPa, 66.25 MPa, 81.83 MPa, and 76.89 MPa, respectively, and can be thus classified as strong rocks (Anon, 1977). Soundness measures resistance to weathering of an aggregate (Chaudhry et al., 2000). The specified upper limits of aggregate used in cement-based concrete and construction range between 10 to 12%. Mean soundness values of the calcitic and dolomitic-marbles are 2.5% and 1.7%, respectively which fall within the permissible range 0-2%; (ASTM C 88, 2001). Thus, the investigated marbles are chemically stable and may not affect the strength of concrete through volume loss, and hence considered suitable for their use in concrete work. The Los Angles abrasion (LAA) evaluates the resistance of an aggregate to abrasion when used as a construction material in highway projects. Average LAA of the calcitic-marble is 34.7% and that for dolomitic-marble its value is 27.8% which lies within the permissible range of 0-40% (ASTM C 131, 2003). A Schmidt rebound hammer or Swiss hammer or concrete hammer test is particularly a surface hardness tester. The Schmidt hammer average rebound numbers for two bulk samples of calcitic-marble are 41.83 and 40.33 while for dolomitic-marble average rebound values are 44.33 and 43.00, which are within acceptable range for use in construction works i.e., >30 (ASTM C 805/C805M-18) and (British Standards, 5508).

The physical parameters of a rock such as specific gravity, water absorption and porosity strongly influence its mechanical response, while these properties are directly controlled by the petrographic characteristics (Sajid et al., 2009, Mustafa et al., 2015). Rocks with low water absorption values have high strength values and high resistance to frost action and chemical weathering processes (Blyth et al., 1974). Thus, the water absorption is a significant physical property when determining the durability of different rocks as construction material (Bell, 2007). The measured water absorption values for calcitic and dolomitic-marbles are 0.57% and 0.41%, respectively which are well below the standard limit for their use as engineering material i.e., <1% (Blyth et al., 1974). A rock having bulk density value of <2.2 gm/cm^3 is categorised to have poor-quality whereas, bulk density value ≥ 2.55 gm/cm^3 is deemed suitable for rock usability as a dimension stone and other engineering purposes (Blyth et al., 1974). The bulk density values for calcitic-marble and dolomitic-marble are 2.690 and 2.813, respectively which are within acceptable limit i.e., ≥ 2.55 gm/cm^3. Rocks possessing >2.55 value of specific gravity, are considered suitable for heavy construction works (Blyth et al., 1974). The values of specific gravity of the marbles from calcitic-marble are 2.732 and 2.846 for dolomitic-marble which are in permissible range i.e., >2.55 (Anon, 1977). The results are shown in Table 1.

Comparison between Calcitic and Dolomitic-Marble

The rock composition and texture control the rock strength. Marble being composed of calcite minerals has a hardness of three on Moh's scale while the hardness of dolomite is slightly high and it is four on Moh's scale. The values of dolomitic-marble physico-mechanical properties have an advantage of high compressive strength (74.13 MPa, 66.25 MPa, 81.83 MPa, 76.89 MPa), very good Los Angles abrasion resistance (27.8%), low water absorption (0.41%), low soluble matter (1.7%), a high bulk density (2.81), and high specific gravity (2.85) in comparison to calcitic-marble which gives compressive strength results (31.90 MPa, 36.39 MPa, 42.32 MPa, 48.10 MPa), Los Angles abrasion (34.7%), high water absorption (0.57%), high soluble matter (2.5%), relatively low bulk density (2.69) and low specific gravity (2.72). Thus, a comparative account of various physico-mechanical properties of calcitic and dolomitic-marbles reveals that the dolomitic-marble ranks higher than calcitic-marble on the durability scale, mainly due to its dense mineral composition.

Conclusion

This study concludes that determination of modal mineralogical composition and textural features are among the most important parameters for evaluating the suitability of a rock as aggregate in construction industry. Petrographic study of carbonate rocks from Mohmand district distinguishes two varieties of marbles from a similar stratigraphic unit i.e., calcitic-marble and dolomitic-marble. The calcitic-marble is declared as innocuous in terms of both ASR and ACR and accordingly recommended for use as aggregate source for the engineering projects in both asphalt and OPC-based concrete.

The dolomitic-marble is classified as deleterious with respect to ACR and as such suitable only in asphalt-based concrete work. The rock cube test further endorses the petrographic study as the dolomitic-marble shows deleterious expansion in rocks due to higher concentration of magnesium, which suggests that it is prone to ACR. Such expansion may significantly reduce the strength and durability of the engineering structure that can cause serious fracturing in concrete, and hence induce critical structural problems that can even result in the demolition of a structure. Therefore, this limits its use in high performance projects. However, it can be used as an aggregate in asphalt works. Moreover, with the exception of soundness value, the dolomitic-marble produces relatively higher values for UCS, specific gravity, bulk density, LA and Schmidt hammer as compared to the calcitic-marble which implies that mineral contents and grain size show strong effects on physico-mechanical properties of rock. The values of various standard physio-mechanical aggregate tests for both the varieties of marbles confirm their suitability according to ASTM standards as a potential aggregate source.

References

Anczkiewicz, R., Burg, J.P., Hussain, S.S., Dawood, H., Ghanzanfar, M., Chaudhry, M. N. (1998). Stratigraphy and structure of the Indus suture in the Lower Swat, Pakistan: NW Himalaya. *Journal of Asian Earth Sciences*, **16,** 225–238. doi: 10.1016/S0743-9547(98)00003-8.

Anjum, M.N., Ali, N., Rehman, Z.U., Ghayas, M. Ahmad, W. (2018). Rock aggregate potential of the limestone units in the Khyber Formation, Khyber Ranges, Pakistan. *International Journal of Economic and Environmental Geology*, **9**(4).

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

Anon. (1979). Classification of rocks and soil for engineering geological mapping, part-1 rock and soil materials. *Bulletin of International Association of Engineering Geologists,* **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. *International Journal of Rock Mechanics and Mining Sciences,* **18**, 85-110.

American Society for Testing and Materials C289-02. (2001). Standard test method for potential alkali-silica reactivity of aggregates (chemical method), *ASTM International, West Conshohocken, PA,* www.astm.org.

American Society for Testing and Materials C-586-05. (2006). Standard test method for potential alkali carbonate reactivity of carbonate rocks as concrete aggregate (rock-cylinder method). Annual book of ASTM standards, **4(**2), . ASTM International, West Conshohocken 6.

American Society for Testing and Materials C-88. (2001). 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

American Society for Testing and Materials 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.

American Society for Testing and Materials C805 / C805M-18. (2018). Standard test method for rebound number of hardened concrete, ASTM International, West Conshohocken, PA, (DOI: 10.1520/C0805_C0805M-18).

American Society for Testing and Materials D2938-95. (2002). Standard test method for unconfined compressive strength of intact rock core specimens. American Society for Testing and Materials C 127. (2001). Standard Test Method for Specific Gravity and Absorption of Coarse Aggregate, Philadelphia, PA.

American Society for Testing and Materials D6683. (2019) Standard test method for measuring bulk density values of powders and other bulk solids as function of compressive stress.

American Society for Testing and Materials C128. (2015). Standard test method for relative density (specific gravity) and absorption of fine aggregate, ASTM International, West Conshohocken, P, USA.

Anjum, M.N, Ali, N., Rehman Z., Ghayas, M., Ahmad, W. (2018). Rock aggregate potential of the limestone units in the Khyber Formation, Khyber Ranges, Pakistan. Int. J. *Econ. Environ. Geol.,* **9**(4).

Bell, F.G.: Engineering Geology, 2nd edition. (2007). Butterworth-Heinemann: An imprint of Elsevier, 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.

British Standards 4408. (1971). Recommendations on Non-destructive method for concrete surface hardness, Part 4.

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

Chaudhry, M.N., Baloch, I.H., Ahsan, N., Majid, C.M. (2000). Engineering properties, mineralogy, alkali aggregate reaction potential and provenance of Lawrencepur sand. Pakistan. Special Issue Pakistan Museum of Natural History, Pakistan Science Foundation, 241–254.

Rex, D., Khan, M.A. (1986). Collision tectonics in the N.W. Himalayas collision tectonics M.P. Coward, A. Ries (Eds.), *Geological Society London Special Publications,* **19**, 203-219.

Coward, M.P., Butler, R.W.H., Chambers, A.F., Graham, R.H., Izatt, C.N., Khan, M.A., Knipe, R.J., Prior, D.J.,Treloar, P.J., Williams, M.P. (1988). Folding and imbrication of the Indian crust during Himalayan collision: Philosophical transactions of the Royal Society of London, Series A, *Mathematical and Physical Sciences,* **326,** 89–116. doi: 10.1098/rsta.1988.0081.

DiPietro, J.A., Ahmad, I., Hussain, A. (2008). Cenozoic kinematic history of the Kohistan fault in the Pakistan Himalaya. Geological Society of American Bulletin, **120**, 1428-1440.

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

Farny, J.A., Kerkhoff, B. (2007). Diagnosis and control of alkali-aggregate reaction in concrete. Portland cement Association, 36 pages.

Hammersly, G.P. (1989). The use of petrography in the evaluation of aggregates concrete, **23** (1).

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

Hewlett P.C. (2006). Lea's chemistry of cement and concrete. Elsevier Ltd.

Lorenzi, G., Jensen, J., Wigum B. (2001). Petrographic atlas of the potentially alkali-reactive rocks in Europe. Version 060701, Partner-project.

Kazmi, A.H., Jan. M.Q. (1997). Geology and Tectonics of Pakistan. Graphic Publisher, Karachi, 554 pages.

Langer, W.H. (2004). Important features of sustainable aggregate resource management, Vilniaus University**, 47,** 99–108.

Mustafa, S., Khan, M. A., Khan, M. R., Hameed, F., Mughal, M. S., Asghar, A., Niaz, A. (2015). Geotechnical study of marble, schist and granite as dimension stone: A case study from parts of Lesser Himalaya, Neelum Valley Area, Azad Kashmir, Pakistan, *Bull. Eng. Geol. Environ.,* **74** (4), 1475-1487.

Prentice, J.E. (1990). Geology of construction materials. Chapman and Hall, London, 202 pages.

Sajid, M., Arif, M., Muhammad, N. (2009). Petrographic characteristics and mechanical properties of rocks from Khagram-Razagram area, Lower Dir, NWFP. Pakistan. *Journal of Himalayan Earth Science,* **42,** 25–36.

Shakoor, A., Bonelli, R. E. (1991). Relationship between petrographic characteristics, engineering index properties, and mechanical properties of selected sandstones. *Bulletin of International Association of Engineering Geologists,* **XXVIII,** 55-71.

Smith, M.R., Collis, L. (2001). Aggregates: Sand, gravel and crushed rock aggregates for construction purpose. *Special Publication, Geological Society,* London, **17**.

Swamy, R.N. (1992). The alkali-silica reaction in concrete. Blackie, Glasgow, Scotland, and London, and Van Nostrand Reinhold, New York.

Treloar, P.J., Coward, M.P., Chamber, A.F., Izzat, C.N., and Jackson, K.C. (1992). Thrust

Geometrics, interference and rotations in the North West Himalayan, in: McClay, K.R., (Ed..), *Thrust Tectonics*. Chapman and Hall, New York, 325-342.