Original Research Paper

IJES *Iranian Journal of Earth Sciences*
Vol. 13, No. 4, 2021, 239-250.
DOI: 10.30495/ijes.2021.1917243.1560

Economic geology of the carbonate rocks from Mesozoic Alpurai group, Peshawar basin, Pakistan

Muhammad Naveed Anjum*[1], Muhammad Ashfaq[1], Sibghat Ullah[2], Muhammad Yaseen[3], Liaqat Ali[4], Jaroslav Prsek[5], Gohar Rehman[1]

1. Department of Geology, University of Peshawar, Pakistan
2. Frontier Works Organization, Pakistan
3. Department of Geology, Abdul Wali Khan University, Marden, Pakistan
4. National Centre of Excellence in Geology, University of Peshawar, Pakistan
5. Faculty of Geology, Geophysics and Environmental Protection, Department of Economic Geology, Kraków, Poland

Received 14 November 2020; accepted 7 February 2021

Abstract

This study aims at evaluating the utilization of carbonate rocks from the Bampokha (Nikanai Ghar Formation) and Sawaldher (Kashala Formation) areas in different industries. Two varieties from the Nikanai Ghar Formation, known under the trade names as Super-white and Sunny-grey, are selected for petrographic and geochemical analysis to evaluate these as a source of calcite ($CaCO_3$), in chemical industries. Petrographically, both the varieties from Bampokha area, are calcitic marbles that exhibit heteroblastic mosaic texture. Geochemical data coupled with X-ray diffraction and petrographic analysis confirms that the Super-white variety is very high purity marble and hence meets the specifications for different chemical industries such as iron and steel industry, glass manufacturing, flue gas desulphurization, soda ash manufacturing and water purification and effluent treatment. In contrast, the high silica (4.1 wt.%) and low calcite contents (<95 wt.%), render the Sunny-grey unsuitable for chemical industries. The rock from Sawaldher quarry, exhibiting an interlocking mosaic pattern, is calcitic marble. Minor amounts of quartz, muscovite and opaque minerals also occur. Comparing the physico-mechanical properties of the aggregate from Sawaldher marble with time-honoured international standards suggests its suitability in concrete work with ordinary portland cement and asphalt. The concrete mix, designed for Class D_2 concrete, has an average 28-days compressive strength value of 518 kg/cm^2 and thus well above the minimum targeted strength of 425 kg/cm^2 for the mentioned class, and hence further endorses that the aggregate can produce strong concretes. This study also suggests the utilization of the studied carbonate resources on industrial scale.

Keywords: *Carbonates, Chemical industries, Aggregate properties, Concrete mix design, Industrial scale*

1. Introduction

Marble is a metamorphic rock formed in response to recrystallization of carbonate rocks such a limestone and dolomite under elevated temperature and pressure conditions below surface zone of weathering (Reeder et al. 1983; Vagenas et al. 2013). Marble can be calcitic ($CaCO_3$) or dolomitic ($CaMg\ (CO_3))_2$ based upon the mineralogy of the protolith. Most of the marble varieties are calcitic in character (Dervos et al. 2005). Marble is extensively utilized as dimension stone and aggregate in both concrete and asphalt works worldwide (Cetin 2003; Onargan et al. 2006). Kore and Vyas (2016), suggested that the coarse aggregate of marble can be used to improve the mechanical properties of conventional concrete mixes. Marble, having high purity, is also a valuable source of carbonates for its use in different chemical industries, including paper, dying, paint, plastic, medicine, cosmetics, animal forage, lime-production, and steel (Carreddu et al. 2009). Chemical analysis of marble is necessary to assess its grade as many industrial applications of marble require constraints on the levels of specific impurities such as SiO_2, Fe_2O_3, Al_2O and MgO (Harrison 1992).

The specifications of limestone for its use in different industries are displayed in Table 1. Pakistan, especially the Khyber Pakhtunkhwa (KP) possesses large reserves of marble, including those belonging to Nikanai Ghar Formation (NGF) and Kashala Formation (KF) of Alpuri Group. The quarries in District Buner from NGF are widely spread and cover an area of ca.700 km^2 (Fahad et al. 2015; Baratian et al. 2018). These are widely extracted as dimension stone and coarse aggregate. Fahad et al. (2015), studied the chemistry and crystal structure of selected marble samples from NGF. Manan and Iqbal (2007), studied the phases and microstructure of some selected marbles from NGF and concluded that the major phase in Super-white marble variety is calcite with a small percentage of quartz as a minor phase. Malahat et al. (2018), assessed various coarse aggregates obtained from different quarries of District Mardan, including the selective carbonate quarries from KF and found them suitable for various engineering applications. However, no work has been carried out so far to investigate the industrial utilization of the Super-white and the Sunny-grey varieties of NGF exposed in Bampokha and the aggregate quality of the newly developed quarries within KF in the Sawaldher area. The carbonates of the KF are evaluated as

----
*Corresponding author.
E-mail address (es): naveed_geo@uop.edu.pk

aggregate in asphalt work as well as concrete mix for their potential use in the on-going 81 km Sawabi-Swat motorway mega project.
Therefore, the first part of this research work, focuses on the geochemical analyses of Super-white and Sunny-grey marble varieties from Bampokha (Fig 1) for assessing them as a source of calcium carbonate in various chemical industries. In the second part, aggregate obtained from carbonates of KF is assessed for its use in concrete and asphalt works, with a special emphasis on examining the effect on strength of the designed concrete mix.

2. Regional Geology

North Pakistan can be divided into three distinct tectonic domains which from north to south include Eurasian plate (north), Kohistan Island Arc or KIA (middle), and Indian plate (south; Searle et al. 1999; Ahmad 2004; Bina et al. 2020). The Main Karakoram Thrust (MKT) marks the boundary between the Karakoram plate and KIA which formed from their collision that took place between 85 to 95 Ma ago (Khan et al. 1993; Schneider et al. 1999; Dipietro et al. 2000). Khan et al. (2009), argued that the Indian plate collided first with KIA (marked by Main Mantle Thrust/MMT) about 65 to 61 Ma ago and later on with Eurasian plate at about 50 Ma ago. Due to this collision, Indian plate was remobilized and metamorphosed during the late Cretaceous-Eocene orogeny (Ahmad et al. 2003; Jehangir Khan et al. 2021). The Indian plate rocks have been divided into tectonostratigraphic zones based on characteristic stratigraphy and faults that bound each zone (DiPietro and Pogue 2004). Peshawar basin lies in between Main Central Thrust (MCT) to the south and MMT to the north and is part of the western hinterland or metamorphic zone. Its tectonic setting is intermediate between a sedimentary fold and thrust belt to the south and a metamorphic terrane to the north (Pogue et al. 1992). Geographically, the study area lies to the north of Peshawar in Buner and Mardan districts. Geologically, these rocks belong to the meta-sediments of the Indian plate, exposed to the north and northwest of the Peshawar Basin. In Buner, rocks of the Nikanai Ghar Formations are investigated for petrography and geochemical analysis from a quarry in village Bampokha, whereas, the rocks sampled for petrography and physico-mechanical properties from Mardan (Sawaldher) belongs to Kashala Formation. The Nikanai Ghar and Kashala Formations which consist of carbonate rocks, being metamorphosed during the late Cretaceous-Cenozoic Himalayan orogeny as a result of collision of the Indian plate with the Kohistan arc-Eurasia (DiPietro and Lawrence 1991; Gharib-Gorgani et al. 2017).

Table 1. Showing general specification of carbonate rocks for use in different industries.

Industrial uses	$CaCO_3$ (min.)	CaO (min.)	SiO_2 (max.)	Al_2O_3 (Max)	Fe_2O_3 (Max)	MgO (Max)	Brightness (min.)
Steel industry [2, 9, 11]	91	51	6	1.3	1	2	
Paper [1, 6]	96	53.76	0.4	0.5	0.1	0.45	93.3
Filler [3,7,10]	96	53.76	1.2	0.3	0.08	0.72	75
Pottery & Porcelain ware [6, 12]	96	53.76	2		0.3	0.5	
Bleaching powder [2, 5]	96.6	54	0.75		0.5	2	
Soda ash & caustic soda [2, 5]	94.6	53	3			1	
Calcium carbide [2, 5, 6, 7]	97	54	1.2	0.5		0.8	
Sugar [3, 5]	89.29	50	2	1.5		1	
Glassware [3, 4, 8, 9]	98	54.85	0.3	0.4	0.1	0.83	
Ceramic [1, 2]	97	54.32	0.12		0.3	3	95.5
Textile production [2, 7]	94	52.64	2.5	2		3	
Food & pharmaceutical [1]	97	54.35	0.12		0.1	0.42	90
Adhesive & sealants [1]	92	51.55	4.5		0.1	1.2	75
Agriculture & animal feed [1, 2]	92	51.55	4.5		0.1	96	81

[1] BGS 2011; [2] Umeshwar 2003; [3] Harben 1995; [4] Emefurieta and Ekuajemi 1995;
[5] Boynton 1980; [6] Mills 1962; [7] Bowen 1957; [8] Hodeg 1938; [9] Gaied 1996;
[10] Elueze et al. 2015; [11] Harrison 1993; [12] American Ceramics Society 1928.

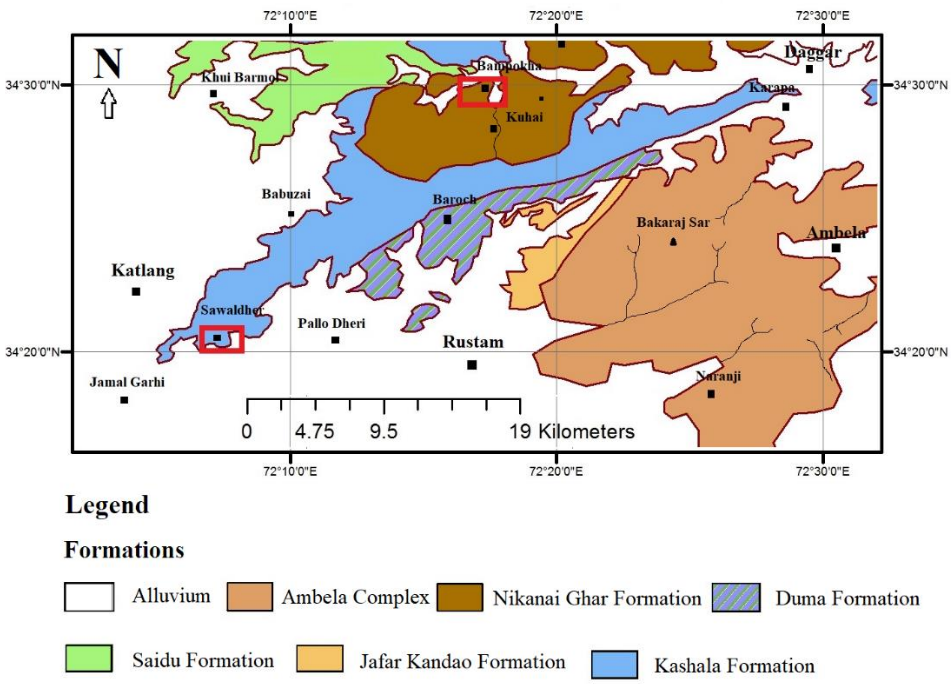

Fig 1. Geological map of the northern boundary of Peshawar basin displaying the study areas represented by red rectangles (modified and reproduced from Hussain et al. 2004).

3. Methodology

Several grab samples were collected from Bampokha quarry for petrographic, mineralogical and geochemical analyses. These samples were cut into thin sections for detailed petrographic analysis. Mineral phases were identified, using the Geol. XRD having built-in software, for the determination of loss on ignition (LIO), powdered samples were heated for an hour at 1000 °C and allowed to get cool. The weight before and after heating was used to calculate the LOI. Representative samples were powdered for mineralogical and geochemical investigations using X-ray diffractometer (XRD) and X-ray fluorescence (XRF) techniques respectively. Samples were finely powdered and subsequently scanned between the range 20 and 65 and the d-spacing values were listed with their intensities using Geol-XRD at Centralized Resource Laboratories of the University of Peshawar. In order to determine engineering properties of Sawaldher source, bulk samples were collected. The bulk samples were crushed in the rock crushing plant as per specifications of American Society for Testing and Materials (ASTM) and National Highway Authority (NHA) to determine Loss Angeles abrasion values (LAAV), soundness, water absorption, porosity, aggregate impact value (AIV), aggregate crushing value (ACV), flakiness and elongation indices and concrete making, at the laboratories of Frontier Works Organization (FWO).

4. Petrography

Marble units of Bampokha (*Nikanai Ghar Formation*) consist of two commercially-known varieties as Super-white and Sunny-grey. Petrographcally, the Super-white consists of coarse-grained calcite whereas, the Sunny-grey consists of medium to coarse calcite grains (Fig 2). In both varieties, calcite is the solely mineral present with no other minerals observed. The grains exhibit rhombohedral cleavage and characteristic twinning (Fig 2A, C) In the Super-white samples, subhedral to euhedral, inequigranular to subequigranular, sutured calcite grains with irregular shapes can be observed. The grain boundaries are fairly straight or curved, sometimes meeting at triple junctions. The overall texture can be termed as heteroblastic mosaic texture (Fig 2A, B). The Sunny-grey samples consist of inequigranular to subequigranular, medium to coarse and sutured calcite grains with heteroblastic mosaic texture (Fig 2C, D).

The fine to medium-grained carbonates from Sawaldher (*KF*) consists predominantly of euhedral to subhedral and equigranular to subequigranular calcite grains, which form a mosaic pattern and thus classifies them as calcitic-marble. Quartz, muscovite and opaque minerals also occur but in minor proportions (Fig 3). The quartz present is mostly strained and can be recognized by its undulose extinction. Opaque minerals generally occur in disseminated form as discrete grains whereas, some can also be observed as fractures infilling (Fig 3C, D). The average modal mineralogical abundances of the carbonates from Sawaldher exhibits that calcite constitutes more than 90 % of the samples by volume (Table 2).

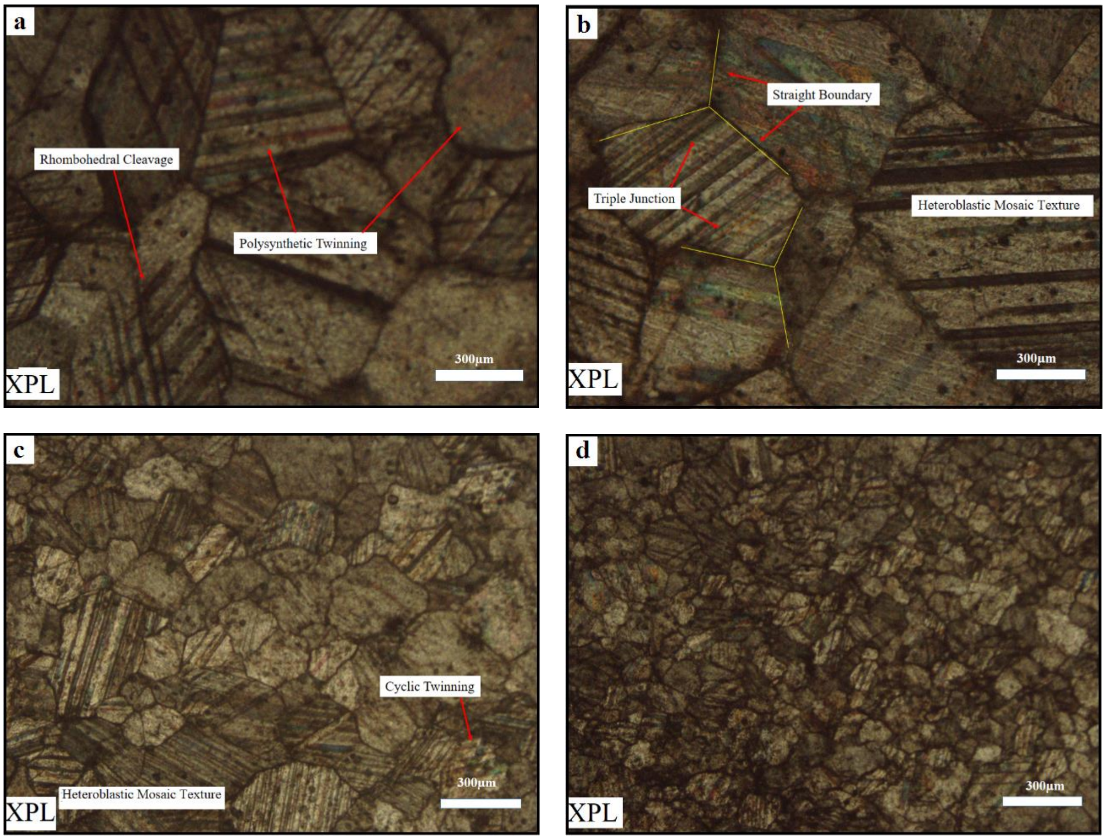

Fig 2. Photomicrographs (XPL) showing petrographic features of Super-white (A and B) and Sunny-grey (C and D) marble varieties.

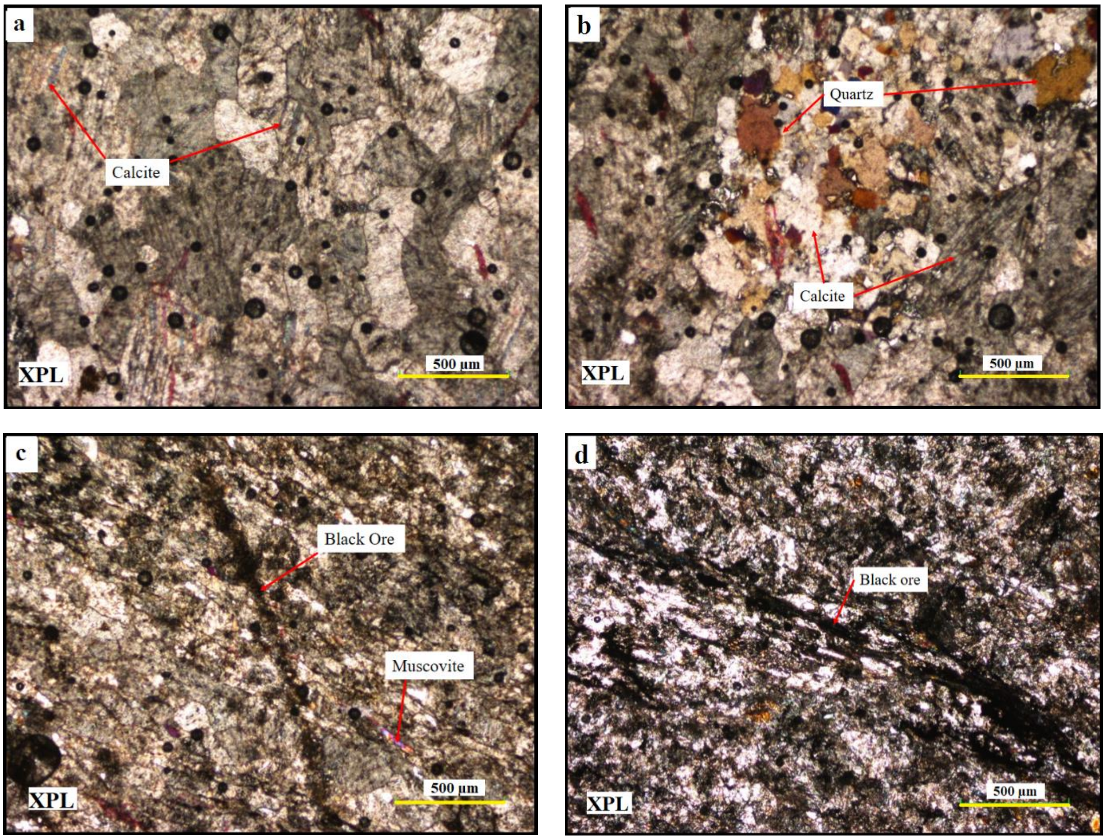

Fig 3. Photomicrographs (XPL) exhibiting petrographic features of Sawaldher marble.

Table 2. Average modal mineralogical composition of Sawaldher Marble

Minerals	Percentage (%)
Calcite	95
Quartz	2
Muscovite	2
Opaque minerals	1

5. Geochemistry / Mineralogy of Bampokha Marble

Prior to the use of a material in any industry, its purity and chemical content is thoroughly investigated with the help of different chemical analysis techniques. The purpose of the quantitative analysis of the Bampokha marble is to determine the concentration of calcium carbonate ($CaCO_3$), as the use of carbonates in majority of chemical industries demand high purity (>98%).

5.1. X-Ray Fluorescence Analysis

Five samples, including 4 from Super-white and one from Sunny-grey varieties, were grinded to fine powders (moisture-free) and accordingly analysed for various oxides (Table 3). Geochemical analysis revealed that CaO concentration in Super-white samples is >55.2 wt.% (55.42–55.73 wt.%), whereas, in Sunny-grey sample, its concentration is 51.5 wt.%. The silica (SiO_2) concentration in Super-white samples ranges from 0.8 to 1.25 wt.%, whereas, in Sunny-grey marble, its concentration is 4.1 wt.%. Minor amounts of Fe_2O_3 (0.04–0.5 wt.%), Al_2O_3 (1.07–1.48 wt.%), and other oxides also occur (Table 3). The LOI (loss on ignition) values of all the samples were also determined, which ranges from 40.9 to 41.65 wt.%.

Table 3. XRF results of the analysed samples

Oxides (wt.%)	Samples				
	Super-white 1	Super-white 2	Super-white 3	Super-white 4	Sunny-grey 1
SiO_2	0.89	1.21	1.07	1.26	4.18
Al_2O_3	1.26	1.12	1.48	1.071	1.20
Fe_2O_3	0.07	0.07	0.04	0.06	0.51
CaO	55.53	55.42	55.73	55.6	51.54
$CaCO_3$	96.83	96.42	96.63	96.6	93.19
MgO	0.82	1.001	0.64	0.85	0.73
SrO	0.05	0.08	0.08	0.06	0.06
TiO_2	BDL	BDL	BDL	BDL	0.04
CuO	0.04	0.04	0.04	0.04	0.04
NiO	0.02	0.03	0.04	0.03	0.04
Ag_2O	BDL	BDL	BDL	0.04	BDL
MnO	BDL	0.03	BDL	BDL	BDL
LOI%	41.3	41	40.9	41	41.65

BDL= below detection level

5.2. X-Ray Diffraction Analysis

XRD technique is utilized for determining the mineralogical phases present in the crystalline samples. Three samples, including two from Super-white and one from Sunny-grey were analysed with X-Ray diffractometer. The results reveal that the peaks in all three samples correspond to calcite mineral which conforms to the data acquired through petrography and chemical analysis (Fig 4).

6. Aggregate properties of Sawaldher Marble

The aggregate from Sawaldher is subjected to various physio-mechanical tests to evaluate its suitability before its use in various engineering structures as per national and international standards. Two bulk samples (KB1 and KB2) were crushed for coarse aggregate from the newly developed quarries of Sawaldher area and the standard test procedures were performed on them. The tests include water absorption (ASTM C 128/C 70) and specific gravity (ASM C 128), aggregate impact value (AIV; ASTM D 5874), aggregate crushing value (ACV; ASTM C131), Los Angeles abrasion (LAA; ASTM C 131) value, soundness (sodium sulphate; ASTM C 88)) and flakiness and elongation indices (ASTM D 4791; Table 4).

Table 4. Results of the various aggregate tests

Sample	Specific Gravity	Water Absorption	AIV (%)	ACV (%)	LAA (%)	Soundness (%)	Flakiness Index (%)	Elongation Index (%)
KB1	2.72	0.47	17	20	27	1.38	12	10.5
KB2	2.71	0.50	19	21	26.2	1.22	15	25
Permissible ranges (ASTM)	2.5-3.0	≤0.6	20-30	35-45	<40	<12	25	25

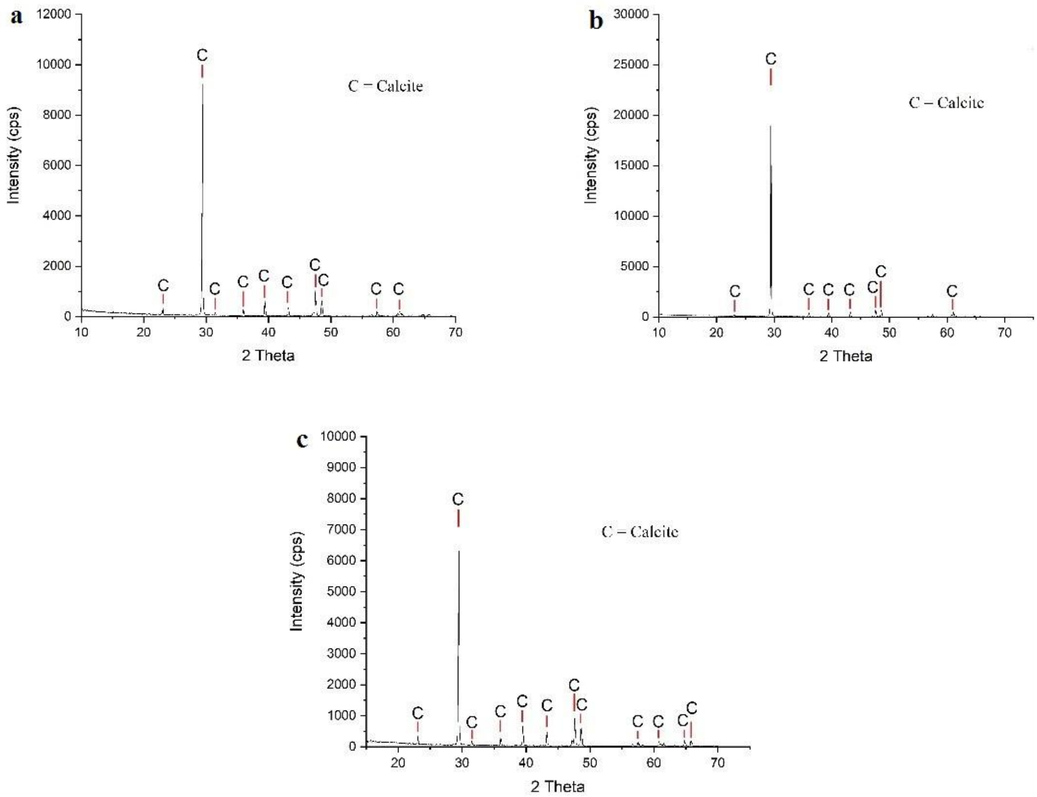

Fig 4. XRD Super-white (A and B) and Sunny-grey (C) marble samples

7. Concrete Mix Design

In a mega construction project, special concrete mixtures are designed for different constructional elements to achieve the desired strength, durability and workability. Concrete consists of cement, fine aggregate, coarse aggregate, and water in a certain prescribed proportion (Alexander and Mindes 2005). By volume approximately 75% of concrete consists of aggregate (Bell 2007). Therefore, the role of aggregate in concrete cannot be taken for granted. In this study, a concrete mix was designed for a specific targeted strength to determine the aggregate capability to produce a concrete of the required strength. For the aforementioned purpose, according to the item 401 of the NHA specifications (Table 5), various classes (A1–A3, B, C, D_1–D_3 and Y) of concrete were designed. A Class D_2 concrete with a minimum targeted 28-days compressive strength of 425 kg/cm^2 was designed for pre-stressed and post-tensioned elements (Table 6).

Table 5. Classes of concrete (NHA general specifications, 1998)

Class of concrete	Min.* cement kg/m^3	Max.** size of coarse aggregate (mm)	28 days compressive strength (Minimum) kg/cm^2	Consistency (mm)	Maximum permissible w/c ratio
A_1	300	20	210	25-75	0.58
A_2	350	25	245	100-150	0.58
A_3	400	38	280	100-150	0.58
B	250	51	170	25-75	0.65
C	275	38	210	25-75	0.58
D_1	450	25	350	50-100	0.40
D^2	500	25	425	50-100	0.40
D_3	550	25	500	50-100	0.40
Y	400	13	210	25-75	0.58
Lean concrete	175	51	100	_	_

*__Min__. = Minimum, **__Max__. = Maximum

7.1. Concrete Mix Proportioning

The mix proportioning is done according to the weight and absolute volume method described in American Concrete Institute (ACI 211.1; 1991). The constituent materials of the concrete and the adopted ratios are presented in Table 5. Mix design calculations for one cubic meter yield are presented in Table 7. For the laboratory trial batch, the weights of the materials were scaled down to produce 0.55 m^3 of concrete. Enough concrete was mixed for obtaining appropriate test results while casting six cylinders (3 for 7-day and 3 for 28-day compressive strength tests).

Table 6. Concrete mix design for class D_2 concrete (ACI 211.1 (1991))

Parameter	Value		Parameters	Value
Specific gravity	2.69*	2.693** (13–25mm)	Water-Cement ratio	0.32
		2.681** (10–16mm)	Cement weight (kg)	600
		2.671** (5–10mm)	Strength	425 kg/cm^2
Absorption (%)	1.485*	0.404** (13–25mm)	Max: Agg: Size	25 mm
		0.447** (10–16mm)	Air content (%)	2.0
		0.509** (5–10mm)	Slump	100–150 mm
Fineness Modulus	2.6*		Admixture (%)	1.3
Cement Sp. Gravity	3.150		Admixture Sp. gravity	1.18
Water source	Well			

*** Fine Aggregate** (Qibla Bandi), ** **Coarse Aggregate** (Sawaldher)

Table 7. Mix design volume of one cubic meter (m^3) yield

Material			Absolute Volume (m^3)	Uncorrected weight (kg)	Corrected Weight (kg)	Trial Batch (0.055 m^3) (kg)
Cement			0.190476	600	600	33.0
Water			0.192000	192	204.1	11.2
Air Voids			0.020000	-	-	-
Admixture (ultra-super 675)			0.006610	7.80	7.80	0.429
Paste			0.409086	-	-	-
Vol. of coarse and fine aggregates			0.590914	-	-	-
Vol. of coarse aggregate			0.407730	-	-	-
Vol. of fine aggregate			0.183183	-	-	-
Coarse agg: 25-13mm		25 %	0.101933	274.5	273.4	15.0
Coarse agg: 16-10 mm	69 %	50 %	0.203865	546.6	544.1	29.9
Coarse agg: 10-5 mm		25 %	0.101933	272.3	270.9	14.9
Fine aggregate	31 %		0.183183	492.8	485.4	26.7
Total weight				2386	2386	131.2

7.2. Slump Test

The slump test is performed (as per ASTM C 143) on freshly mixed concrete to evaluate its workability. Workability is defined as the ability of concrete to flow. Workability has a direct impact on the strength, quality and appearance of the concrete. Results of different samples are displayed in the Table 8.

7.3 Compressive Strength Test

Compressive strength is the ability of a material to carry the loads on its surface until it starts cracking or deflection. In this test, a compressive axial load is applied on moulded cylinders (6×12 inches) until they fail by fracturing (Table 9).

Table 8. Results of the slump test performed on the concrete at different time intervals

Slump samples	Fresh	After 15 min.	After 30 min.	After 45 min.
01	185 mm	165 mm	150 mm	135 mm
02	184 mm	163 mm	151 mm	134 mm
03	184 mm	164 mm	149 mm	136 mm

Table 9. Showing compressive strength values

	Required strength (28-days)			Min: 425 kg/cm^2	
	Date of casting			13/12/2018	
Testing Date	Age (days)	Load (kg)	Area (cm^2)	Strength (kg/cm^2)	Average Strength (kg/cm^2)
20/12/2018	7	78000	182.4	427.6	422.3
		76300		418.3	
		76800		421.1	
10/01/2019	28	96800	182.4	530.7	518.4
		95000		520.8	
		91900		503.8	

8. Discussion

8.1. Industrial Suitability of Bampokha Marble

Marble is used in different industries as a source of calcite according to its geochemical composition (Table 1). As indicated by the CaO (wt.%) value of >55.2%, the calcium carbonate ($CaCO_3$) content in Super-white samples is >98.5 wt.% whereas silica (SiO_2) concentration is low (0.89–1.26 wt.%) which conforms to their very high purity class according to the classification of Cox et al. (1977) and Harrison (1992; Table 10). Such high-class carbonate rock is often called as industrial marble (BGS 2006) On the other hand, lower concentration of $CaCO_3$ (<98 wt.%) and higher amount of 4.1 wt.% silica (SiO_2) in Sunny-grey marble assigns a medium purity class (Harrison 1992) and hence renders it unsuitable for use in majority of chemical industries.

The XRD analysis of the Super-white marble, being compatible with the petrographic examination, confirms that calcite is the only mineral phase present thus suggesting a pure calcitic composition with no other identifiable phases. No silicate phases are detected in Sunny-grey marble and that is why calcite is the only identifiable phase. The SiO_2 (<5 wt.%) and Al_2O_3 (<2 wt.%) shown by XRF results in the Sunny-grey marble sample were not detected by the X-ray diffractometer in the form a mineral phase, which may be attributed to the occurrence of minor concentration of clays in the analysed sample. Based on the chemical composition, the Super-white variety is considered suitable for its use in different industries, i.e., iron and steel industry, flue gas desulphurization, soda ash manufacturing, glass manufacturing, water purification and effluent treatment (Cox et al. 1977; Tables 1 and 10).

Table 10. Classification of marble/limestone by purity (Cox et al. 1977: Harrison et al. 1998).

Category	$CaCO_3$ (wt.%)	CaO (wt.%)
Very high purity	>98.5	>55.2
High purity	97.0 – 98.5	54.3 – 55.2
Medium purity	93.5 – 97.0	52.4 – 54.3
Low purity	85.0 – 93.5	47.6 – 52.4
Impure	<85.0	<47.6

8.2 Aggregate Suitability of Sawaldher Marble

The petrographic analysis of marble samples from Sawaldher quarry reveals that calcite is the dominant mineral constituent and a narrow range of variations is observed in terms of mineralogical composition and texture. Rocks containing physically strong minerals tend to behave strongly whereas, those composed of low strength minerals are weak (Tugrul and Zarif 1999). The investigated marble can be considered relatively medium in strength as compared to rocks having hard minerals. The intergranular contact and shape of mineral grains in a rock also affect its strength (Shakoor and Bonelli 1991). The grains of the investigated marble are irregular in shape due to which the grains are closely packed and thus forms a mosaic pattern. The close packing of grains, therefore, could have imparted strength to the rock as a whole. Apart from calcite, small amounts of mica (2%) and strained quartz (2%) are also observed in the studied samples, which are considered deleterious and harmful for ordinary portland cement (OPC) concretes if they occur in higher concentrations (Kosmatka et al. 2002). According to Gogte (1973), rocks containing ≥40% strained quartz are highly reactive, whereas those with between 30% and 35% are moderately reactive. However, the concentration of such deleterious material in the studied samples is in innocuous range and hence safe from ASR.

The different mechanical and physical values of the Sawaldher aggregate are in accordance with the suitable ranges of standard values and hence classify it as suitable for use as coarse aggregate. The water absorption value in percentage for the KB1 sample is 0.4% and KB2 is 0.5%. According to BS 5337 and ASTM C 128, the maximum permissible range of water absorption is 3% and 0.6% respectively.

Rocks having specific gravity ≥2.5% are considered more suitable for heavy construction (Blyth and Freitas 1974). Neville (2011), states that the specific gravity of coarse aggregates should range from 2.5 to 3.0. Good quality rocks possess high specific gravity and low water absorption. The specific gravity values for KB1 and KB2 are 2.72 and 2.71, respectively and hence fall within the standard ranges.

The soundness value for sample KB1 is 1.38%, whereas for KB2, it is 1.22%. The ASTM C 188 specifies the upper limit of the permissible range of soundness for coarse aggregate to be 12% (using sodium sulphate). Hence, the aggregate is classified as durable and suitable.

The Los Angeles abrasion test values for KB1 and KB2 are 27% and 26.2%, respectively. These values are within safe limits for all types of constructional works because the maximum specified limit for Los Angeles abrasion is suggested 30% as per BS 882 (1992).

Aggregate crushing value is a numerical index of the strength of the aggregate. The crushing value test performed on the aggregates give values of 20% for KB1 and 21% for KB2, which are well within the suitable range (30% for wearing surfaces and 45% for aggregate used in concrete (ASTM C 131).

According to ASTM D 5874, the upper limit of the permissible range for heavy concrete floor finishes is 25% and for concrete used in pavement wearing surfaces is 30 %, whereas for all other construction works the upper limit is 45%. The aggregate impact values (AIV) for the studied samples KB1 and KB2 are 17% and 19%, respectively, which indicate that the studied rocks fall in the strong category (Tables 4 and 11).

Table 11. Classification of aggregate on the basis of impact value as per Indian Road Congress (IRC 2000)

AIV	Classification
<10%	Exceptionally strong
10-20%	Strong
20-30%	Satisfactory for road surfacing
>35%	Weak for road surfacing

The Flakiness index values for KB1 and KB2 samples are 12% and 15%, respectively while the elongation index values for KB1 and KB2 samples are 10.5% and 15%, respectively which also lies within the suitable range as per ASTM D 4791 (maximum limit = 40%).

8.3 Concrete Mix Design

The concrete mix for class D_2 concrete was proportioned in accordance with ACI 211.1 (1991), with a minimum required 28-days compressive strength of 425 kg/cm^2. The class D_2 concrete is used in pre stressed and post-tensioned elements. The consistency of the concrete calculated after every 15, 30 and 45 minutes suggests that the concrete is workable. The hardened concrete specimens (cylinders) were subjected to compression, and their compressive strengths were calculated. The average 7-days compressive strength of the three specimens is 422 kg/cm^2, while the average 28-days compressive strength of the other three specimens is 518 kg/cm^2. The three specimens fractured well above the minimum targeted value of 425 kg/cm^2 after 28 days, suggesting that the concrete is suitable for the required application.

The role of aggregate in a concrete cannot be ignored as the properties of aggregate influence the stress concentrations in the composite material when the concrete is under compression. Elaxander and Mindes (2005), states that the strength of the concrete depends on the strength of the binder phase, aggregate phase and the interfacial bond between the phases. Kaplan (1959 a) concluded that with careful selection of aggregates without changing the mix proportions, an increase in compressive strength of concrete can be witnessed. Neville (2011), also agrees to the conclusion that a strong relationship exists between the aggregate properties and strength of the concrete and states that the concrete strength is greatly affected by the mechanical strength of the aggregate, its absorption and bonding with the cement. Quiroga (2003) and Bell (2007), argues that the surface texture of aggregate plays a role in bonding between the cement and aggregates; a rough surface creates a good bond whereas a smooth surface creates a weak bond. It is, therefore, fair enough to say that the better strength of concrete could be also be attributed to the surface roughness (jagged surfaces) and close packing of mineral-grains of the studies aggregate.

9. Conclusions

Following are the conclusions derived from this study.

i) The Super-white marble variety from the Bampokha quarry (NGF) consists of more than 98.5 wt.% $CaCO_3$ and a minor amount of quartz which indicates a very high purity (>98.5 wt.%) and less quartz content. The chemical composition meets the specification for the targeted chemical industries, including iron and steel industry, soda ash manufacturing, glass manufacturing, flue gas desulphurization and water purification, and effluent treatment.

ii) The Sunny-grey marble variety belonging NGF do not meet the specification for chemical industries due to its low $CaCO_3$ content (<98% for various industries) and high amount of SiO_2 (>3%).

iii) Petrographically, the carbonate rocks from newly developed quarries in Sawaldher (KF) consist of fine to medium grained re-crystallized calcite as the dominant mineral phase while minor to trace amount of quartz, muscovite, opaque minerals and carbonaceous material also occur thus classifying them as marble.

iv) The strained and poly-crystalline quartz which are considered reactive for causing alkali-silica reactivity (ASR), occur in the permissible range. The Sawaldher marble aggregate, therefore, falls as innocuous for use in ordinary portland cement concretes.

v) The physio-mechanical properties of the coarse aggregate of Sawaldher marble lie in the permissible ranges as per international and national standards. Hence, these rocks can be utilized in highway projects, particularly in the Swat motorway project, in both asphalt and concrete purposes.

vi) The average 28-days compressive strength value of the concrete developed for Class D_2 from Sawaldher quarry amounts 518 kg/cm^2, thus showing a higher value than the minimum required 28-days compressive strength of 425 kg/cm^2. This higher strength value is attributed to the higher mechanical strength, low water absorption, and rough surfaces, close mineral packing, and angular shapes of the Sawaldher aggregate.

References

Ahmad I, Jan MQ, DiPietro JA (2003) Age and Tectonic Implication of Granitoids from the Indian Plate of Northern Pakistan *Journal of the Virtual Explorer* 11: 21-28.

Ahmad SA (2004) Geology, Geochemistry and Petro-Genesis of the Neoproterozoic Indian Shield Extension in Pakistan Ph.D. thesis, Institute of Geology, University of Punjab, Lahore, Pakistan.

Aitcin PC (2003) The Durability of High-Performance Concrete: a Review. *Cement and Concrete Composites* 25 (4-5): 409-420.

Akubulut H, Gurer C (2007) Use of Aggregates Produced from Marble Quarry Waste in Asphalt Pavements. *Building and Environment* 42: 1921-1930.

Alexander M, Mindess S (2005), Special aggregates and special concretes, *Aggregates in concrete* 361-368.

American Ceramics Society (1928) Standard specifications for materials, Ceramic whiting: American Ceramics Society Journal 11(6), 378p.

American Concrete Institute 211.1 (1991) Standard Practice for Selecting Proportions for Normal, Heavy weight and Mass Concrete. American Concrete Institute, Farmington Hills, Michigan.

American Society for Testing and Materials C 125 (2007) Standard Terminology Relating to Concrete and Concrete Aggregates, American Society for Testing and Materials, Philadelphia, Pennsylvania, USA.

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.

American Society for Testing and Materials C131 (2020) Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine, ASTM International, West Conshohocken, PA, USA.

American Society for Testing and Materials C143 (2020) Standard Test Method for Slump of Hydraulic-Cement Concrete, ASTM International, West Conshohocken, PA, USA.

American Society for Testing and Materials C88, (2018) Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate, ASTM International, West Conshohocken, PA, USA.

American Society for Testing and Materials D 692 (2003) Standard Specification for Coarse Aggregate for Bituminous Paving Mixtures, American Society for Testing and Materials, Philadelphia, Pennsylvania, USA.

American Society for Testing and Materials D4791 (2019) Standard Test Method for Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate, ASTM International, West Conshohocken, PA, USA.

American Society for Testing and Materials D5874 (2016) Standard Test Methods for Determination of the Impact Value (IV) of a Soil, ASTM International, West Conshohocken, PA, USA.

Baratian M, Arian MA, Yazdi A (2018) Petrology and petrogenesis of the SiahKuh intrusive Massive in the South of KhoshYeilagh, *Amazonia Investiga*, 7 (17), 616-629

Bell FG (2007) Engineering Geology, 2nd Edition, Butterworth-Heinemann, an Imprint of Elsevier, United Kingdom.

Bina M, Arian MA, Pourkermani M, Bazoobandi MH, Yazdi A (2020) Study of the petrography and tectonic settings of sills In Lavasanat district, Tehran (north of Iran), *Nexo Revista Cientifica*, 33(2), 286-296, DOI: https://doi.org/10.5377/nexo.v33i02.10768

Blyth FGH, De Freitas MH (1974) ELBS and Edward Arnold; London.

Bowen OE (1957) Limestone, dolomite, and lime products, in Mineral commodities of California: California Div. *Mines Bulletin* 176, 293-306.

Boynton RS (1980) Chemistry and technology of lime and limestone. 2nd Ed. New York, John Wiley and Sons Inc., 300p.

British Geological Survey (2006) Mineral Planning Factsheet: Limestone, British Geological Survey 9p.

British Geological Survey (2011) Industrial Minerals, High purity limestone.

British Standard Institution (1976) The Structural Use of Concrete for Retaining Aqueous Liquids, BS 5337, London, UK.

British Standard Institution (1992) Specifications for Aggregates from Natural Sources for Concrete, BS 882, London, UK.

Bureau of Indian Standards (1970) Indian Standard Specification for Coarse and Fine Aggregates from Natural Sources for Concrete. IS 383. New Delhi 110002, 2nd Revision, 9th Reprint September 1993.

Careddu N, Marras G, Siotto G, and Orru G (2009) Recovery and reuse of marble powder conteined in marble slurry waste. In Symposium Papers of Evaluation of Marble Wastes and Decreasing Environmental Effects (M. Ayhan, A. Karakus, M. O ¨ zdemir Aydin, Eds.), Diyarbakir, Turkey, 62–69.

Çetin T (2003) Marble potential, production and export of Turkey, *Gazi University Journal of the Faculty of Education* 23: 243-256.

Chessin H, Hamilton WC, Post B (1965) Position and Thermal Parameters of Oxygen Atom in Calcite, *Acta Crystallographica* 18:689-693.

Cox FC, McC Bridge D, Hull, JH (1977) Procedures for the Assessment of Limestone Resources, Mineral Assessment Report, Institute of Geological Sciences, No. 30.

Dervos CT, Mergos JA, Iosifides AA (2005) Characterization of Insulating Particles by Dielectric Spectroscopy: Case Study for Calcium Carbonate Powders, *Material Letters* 59: 2842-2849.

DiPietro J, Hussain A, Ahmad I, Khan MA (2000) The Main Mantle Thrust in Pakistan: its Character and Extent. *Geological Society, London, Special Publications* 170: 375-393.

DiPietro JA, Lawrence RD (1991) Himalayan Structure and Metamorphism South of the Main Mantle Thrust, Lower Swat, Pakistan, *Journal of Metamorphic Geology* 9: 481-495.

DiPietro JA, Pogue, KR (2004) Tectonostratigraphic Subdivisions of the Himalaya: A View from the West. Tectonics**,** 23, TC5001, da: 10.1029/2003TC001554, 20p.

Elueze AA, Jimoh AO, Aromolaran OK (2015) Compositional characteristics and functional applications of Obajana marble deposit in the Precambrian basement complex of central Nigeria. *Ife Journal of Science* 17(3): 591-603.

Emefurieta WO, Ekuajemi, VO (1995) Lime Products and Economic Aspects of Igbeti, Ososo and Jakura Marble Deposit in SW- Nigeria. *Journal of Mining and Geology* 31(1):79-89.

Fahad M, Iqbal Y, Riaz M, Ubic R, Redfern S (2015) Metamorphic Temperature Investigation of Coexisting Calcite and Dolomite Marble-Examples from Nikani Ghar Marble and Nowshera Formation (Peshawar Basin, Pakistan), *Journal of Earth Sciences*,

Fathi IS (2014) Effect of Using Crushed Limestone in Concrete Mixes as Fine Aggregate on Compressive Strength and Workability. CBEE, 40-44.

Gaied M (1996) Geological and Geotechnical Study of Eocene Useful Materials from the North-Eastern Edge of the Kasserine Palaeo-Relief (Central Tunisia). Ph.D.Thesis, Faculty of Sciences of Tunis. Tunisia. 135p.

Gharib-Gorgani F, Ashja-Ardalan A, Espahbod MR, Sheikhzakariaee SJ, Yazdi A (2017) Petrology of Mg-bearing Meta Ophiolite Complexes of Qaen-Gazik, Eastern Iran, *National Cave Research and Protection Organization* 4(1), DOI:10.21276/ambi.2017.04.1.ga01

Gogte BS (1973) An Evaluation of Some Common Indian Rocks with Special Reference to Alkali Aggregate Reactions, *Engineering Geology* 7:135-154.

Haq IU (2012) To Investigate the Suitability of Coarse Aggregate Sources Available in District Nowshera for Use in Ordinary Structural Concrete, Unpublished MS Thesis, University of Engineering and Technology, Peshawar.

Harben PW (1995) Silica and quartz, *The Industrial Mineral Handbook:* 156-161.

Harrison DJ (1992). Industrial Minerals Laboratory Manual: Limestone, British Geological Survey Technical Report WG/92/29.

Harrison DJ (1993) High-purity limestones in England and Wales, *Quarterly Journal of Engineering Geology* 26: 293-303.

Harrison DJ, Inglethorpe SDJ, Mitchell CJ, Kemp SJ, Chaodumrong P and Charusribandhu M (1998) Procedures for the rapid assessment of limestone resources. *British Geological Survey Technical Report* WC/98/1, 120.

Hodge ET (1938). *Market for Columbia River Hydroelectric Power Using Northwest Minerals: Northwest limestones. 2 v* (Vol. 2). Corps of Engineers, US Army, North Pacific Division.

Hussain A, DiPietro JA, Pogue KR, Ahmad I (2004) Geological Map of the 43B Degree Sheet, NWFP, Pakistan, Degree Sheet Map Series, Geological Map No. 11, Geological Survey of Pakistan.

Indian Roads Congress (2000) Guidelines on Quality Systems for Roads. Special Publication, New Delhi, India.

Iqbal, MM, Gondal, Choudhry, MN, Khan ZK, Ahsan, N (2009) Allai Aggregate for Rehabilitation and Reconstruction of October 8, 2005 Earthquake Affected Allai-Banan Area, NWFP, Pakistan, *Geological Bulletin of Punjab University* 44:43-54.

Jehangir Khan M, Ghazi S, Mehmood M, Yazdi A, Naseem AA, Serwar U, Zaheer A, Ullah H (2021) Sedimentological and provenance analysis of the Cretaceous Moro formation Rakhi Gorge, Eastern Sulaiman Range, Pakistan, *Iranian Journal of Earth Sciences* 13 (4), 252-266

Kaplan MF (1959a) Flexural and Compressive Strength of Concrete as Affected by the Properties of Coarse Aggregates, Proceeding ACI 55: 1193-1207.

Khan MA, Jan MQ, Weaver BL (1993) Evolution of the Lower Arc Crust in Kohistan, N. Pakistan: Temporal Arc Magmatism Through Early, Mature and Intra-arc Rift Stages. In: Treloar P.J, Searle M.P (eds) Himalayan Tectonics, *Geological Society, London, Special Publications* 74: 123–138.

Khan SD, Walker DJ, Hall SA, Burke KC, Shah MT, Stockli L (2009) Did Kohistan-Ladakh Island Arc Collide First with India?. *Geological Society of America Bulletin* 121: 366–384.

Kore SD, and Vyas AK (2016) Impact of Marble Waste as Coarse Aggregate on Properties of Lean Cement Concrete, Case Studies in Construction Materials 4: 85-92.

Kosmatka SH, Kerkhoff B, Panarese WC (2002) Design and Control of Concrete Mixtures, EB001, 14th Edition, Portland Cement Association, Skokie, Illinois, USA.

Lopez-Buendia, AM, Climent V, Verdu P (2006) Lithological Influence of Aggregate in the Alkali Carbonate Reaction. Cement and Concrete Research, Elsevier Ltd. Valencia, Spain, 36.

Malahat F, Naseer A, Bilqees R (2018) Engineering and Mineralogical Assessment of Coarse Aggregates Used in District Mardan, *Journal of Himalayan Earth Sciences* 51 (1): 34-43.

Manan A, Iqbal Y (2007) Phase, Microstructure and Mechanical Properties of Marbles in North western Part of Pakistan: Preliminary Findings, *Journal of Pakistan Material Society* 1 (2): 68-72.

Mill JW (1962) High-calcium Limestones of Eastern Washington. Bulletin No. 48. Washington. USA. 78p.

National Highway Authority (1998) General Specifications. Ministry of Communications, Government of Pakistan.

Neville AM (2011) Properties of concrete, 5th Edition; Pearson Education Limited, Essex. England.

Onargan T, Köse H, Deliormanl AH (2006) Marble, 4th Edn. Chamber Mining Engineers of Turkey, Ankara, Turkey.

Pogue KR, Wardlaw BR, Harris AG, Hussain A (1992) Palaeozoic and Mesozoic Stratigraphy of Peshawar Basin, Pakistan: Correlations and Implications, *Geological Society of America Bulletin* 104: 915-927.

Quiroga PN (2003) The effect of the aggregates characteristics on the performance of Portland cement concrete, The University of Texas at Austin.

Reeder RJ, Wenk HR (1983) Structure Refinements of Some Thermally Disordered Dolomites, *American Mineralogist* 68: 769-776.

Schneider DA, Edwards MA, Kidd WSF, Khan, MA, Seeber L, Zeitler PT (1999) Tectonics of Nagna Parbat, Western Himalaya: Synkinematic Plutonism within the Doubly Vergent Shear Zones of a Crustal Scale Pop-up Structure, *Geology* 27: 999-1002.

Searle MP, Cox JS (1999) Tectonic Setting, Origin and Obduction of the Oman ophiolite. *Geological Society of America Bulletin* 111: 104-122.

Shakoo A, Bonelli RE (1991) Relationship between Petrographic characteristics, Engineering Index Properties, and Mechanical Properties of Selected Sandstones. *Bulletin of International Association of Engineering Geology* XXVIII (1): 55-71.

Singh M, Srivastava A, Bhunia D (2016) Potential Applications of Marble Dust in Industrial use by Characterization Techniques- A Review. *International Journal of Advanced Structures and Geotechnical Engineering* 5 (3): 99-106.

Tugral A, Zarif, IH (1999) Correlation of Mineralogical and Textural Characterization with Engineering Properties of Selected Granitic Rocks from Turkey. *Journal of Engineering Geology*, 51: 303-317.

Umeshwar P (2003) Economic Geology. New Delhi: Satish Kumar Jain for C.B.C: 204-207

Vagenas NV, Kontoyannis CG (2013) A Methodology for Quantitative Determination of Minor Components in Minerals Based on FT-Raman Spectroscopy: The Case of Calcite in Dolomitic Marble. *Vibrational Spectroscopy* 32: 261-264.