Physical characterization and alkali carbonate reactivity (ACR) potential of the rocks from Bauhti Pind and Bajar area Hassan Abdal, Pakistan

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Abstract

This study is conducted to evaluate aggregate characteristics and alkali carbonate reactivity (ACR) potential of carbonate rocks of the Bouhti Pind and Bajar area, Hassan Abdal, Pakistan. Physical and chemical tests were performed to assess aggregate suitability. Mean specific gravity (2.65–2.65), water absorption (0.51–0.68%), Los Angeles abrasion (24.78–26.10%) and sulphate soundness values (2.86–4.25%) of the carbonate rocks of these areas are within specified limits of their respective standards. Petrographic studies of Bajar area reveal the presence of 96.3% calcite, 2% clays, 1% hematite and 0.7% quartz. These rocks do not contain dolomite and show no expansion in rock cylinder test. Therefore, the aggregate is not prone to ACR and can be used in cement concrete. Rocks of Bouhti Pind area have mean 92% calcite, 3.8% dolomite, 2% clays, 1.2% hematite and 1% monocryalline quartz. The amount of deleterious minerals specifically dolomite and clays are below the maximum allowed limit to initiate ACR. However, one of the rock cylinders shows 0.043% expansion which is below threshold limit of 0.10% to cause ACR as specified in ASTM C-585. Hence, these carbonate rocks qualify physical characterization and ACR tests and can be used in the construction of roads and in cement concrete.

Keywords Physical characterization · Alkali carbonate reactivity · Petrographic studies · Pakistan

1 Introduction

Aggregates are naturally occurring materials that should be inert and durable which can form firm bond when used as a source of construction material in cement concrete [25, 47]. Rock-crushed aggregate is produced for utilization in cement and asphalt concrete, in roads, railways as well as riprap material [1, 10, 18, 27, 43]. Aggregate is an important constituent in cement and asphalt concrete. Cement concrete contains about 70% aggregate, and strength of concrete depends upon the durability of the aggregate [42]. The construction industry primarily required a huge amount of aggregates [17, 44]. In developing countries, aggregate plays a vital role in the construction industry. But in Pakistan, this is one of the most neglected sectors

where only limited aggregate sources have been explored [23, 50]. The construction industry of Pakistan uses mostly carbonate aggregate which is abundantly available in various parts of the country [35, 38, 45, 51]. Margala Hill Limestone, Kirana Hills of Sargodha and gravels of Attock area are common source of aggregate used in engineering projects [2, 9, 31]. Meanwhile, limestone of Salt Range, Kohat and Hazara areas is also considered as significant aggregate source [15, 16, 42, 50]. On the other hand, Malkani and Mahmood [28, 29] reported vast and huge deposits of easily mineable limestone deposits from Sulaiman, Kirthar and Balochistan basins.

An aggregate should possess desirable mechanical, chemical and mineralogical properties for use as aggregate source [30]. Different tests like water absorption,

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specific gravity, Los Angeles abrasion values and sodium sulphate soundness are carried out to determine the suitability of the material, whereas modal mineralogical composition of the aggregate is determined to assess the presence of deleterious materials such as dolomite, clays and strained quartz found in carbonate aggregate. These minerals constituents control physical and chemical characteristics of an aggregate and can interact with alkali hydroxides in the cement to cause deleterious expansion as well as deterioration in structure and swelling in the concrete fabric, ultimately failure of the structure [33, 46].

Alkali-carbonate reaction (ACR) occurs when dolomite of carbonate aggregate reacts with alkalis hydroxides of the cement in the presence of moisture. The dolomite becomes dedolomitized as brucite mineral and exerts tensile stress which produces cracks. This allows the entry of water in the presence of clay minerals resulting in failure of structure [13, 19, 21, 46]. The occurrence of dolomite and clays can be found out by petrographic technique, while expansion behaviour can be determined through Rock Cylinder method (ASTM C-586).

Carbonate rocks of the Potwar, Kohat, Salt Range, Hazara and Kala Chitta Range were investigated by many researchers (e.g. [16, 20, 22, 42]). But little attention was given to the aggregate characteristics of the carbonate rocks of these areas. Engineering properties of aggregate of the Margala Hill Limestone and Lockhart Limestone of Rumli and Hazara area were presented by Naeem et al. [31] and Sadiq et al. [37]. Chaudhry et al. [10], Ahsan et al. [1] and Zaidi et al. [50] discussed the physical characterization of aggregates of Salt Range and Kirana Hills, Sargodha area. However, physical and chemical characteristics of the carbonate rocks of Bouhti Pind and Bajar area have not been documented in the literature. Moreover, ACR potential of these dolomitic carbonate rocks has not been presented prior to this contribution. Hence, there was a dire need to investigate the physical and chemical properties and ACR potential of the carbonate rocks of Bouhti Pind and Bajar area to assess their suitability as aggregate sources for use as construction material for engineering projects.

2 Tectonics

The Bouhti Pind and Bajar area lie in Cambellpur Basin, Lesser Himalaya, NW Pakistan [48]. The Lesser Himalaya is delimited by Main Boundary Thrust (MBT) in the south and Main Central Thrust (MCT) in the north [36, 39]. The Bouhti Pind and Bajar areas are located near Hassan Abdal in the north-east of Kala Chitta Range and in the east of Attock Cherat Ranges [8]. The area falls in active folding and thrusting zone in the foreland of Himalayan

mountain belt in Pakistan (Fig. 1). Hassan Abdal lies in NE of Kherimar Hills and south of Gandhar Range. Gandhar Range and Kherimar Hills are situated in the north of Main Boundary Thrust. Kherimar Hills are truncated by Nathiagali Thrust which changes into Hassartang Fault in the west [14, 26]. Gandhar Range is located in the north-east of Kala Chitta Range and in the north of Hassan Abdal/Kherimar Hills (Fig. 1). The Kala Chitta Range is an elongated EW trough situated along the north-western margin of the Indo-Pak Plate [32]. The Attock-Cherat Range is situated in the north of the Kala Chitta Range [14]. Panjal Thrust truncates in Cambellpur Basin north-east of Gandhar Range which extends to Khairabad Thrust in the west. Kala Chitta Range is bounded by MBT in the southern side, which further converts into Murree Thrust in the east and Hassartang Fault in the west [49].

3 Stratigraphy

Hazara Formation, Samana Suk Formation, Lockhart Limestone and Patala Formation are exposed in Bouhti Pind and Bajar area, Hassan Abdal. The Hazara Formation is the oldest (Precambrian) rock unit. The Samana Suk Formation of Jurassic age unconformably overlies the Hazara Formation which is overlain by Lockhart Limestone of Palaeocene age. However, due to erosion, the Patala Formation is not exposed in this area [20]. The Hazara Formation predominantly comprised of slate and phyllite. In Bouhti Pind and Bajar area, grey to dark-grey, medium to thick-bedded limestone of Samana Suk Formation is exposed. The limestone presents yellowish-brown weathering colour. At a few places, the limestone is massive shows jet-black colour. However, the limestone presents brittle behaviour. Yellowish dolomitic patches are present in the limestone of Bouhti Pind area. The limestone contains white calcite veins, fractures and joints. The limestone shows nodular behaviour in the study areas. Solution weathering is commonly found in the carbonate rocks of the Bouhti Pind area. The Lockhart Limestone consists of light-grey to grey, medium to thick-bedded, massive limestone [40]. In Trans-Indus Range, the Lockhart Limestone is greyish, medium-bedded with minor marl and calcareous shale. In the Hazara and Kala Chitta area, the dark-grey limestone is found with shale and intercalations [40]. The limestone is of bituminous nature that gives odour on fresh surface. This limestone is well developed in the Kohat-Potwar area [20, 22]. The Hassan Abdal hills are composed of Jurassic-Palaeocene rock units mainly Lockhart Limestone which lies on Samana Suk Formation. The Wah Hill mainly consists of Lockhart Limestone [11].

Fig. 1 Reveals tectonic map and location of the study area

4 Methodology

Representative carbonate rock samples of Bouhti Pind and Bajar area were washed and dried in an oven at 110 °C for 24 h. Physical and chemical tests were performed according to the specifications of their respective standards. Specific gravity, water absorption, Sulphate soundness and Los Angeles abrasion value were determined by using ASTM standards (C-127, C-88 and C-131-69). The results are presented in Table 1.

4.1 Petrography [6]

The carbonate rock samples of Bouhti Pind and Bajar area were washed and cut into thick slabs by using diamond cutter. These slabs were washed and grinded to make smooth surfaces and mounted on glass slide of 1 mm thick with 26 × 46 mm dimension, with the help of Lack-side-70 epoxy resin that has 1.54 index of refraction. These mounted slabs were grinded with 600- and 800-mesh SiC powders to reduce their thickness. Final grinding and

Table 1 Specific gravity, water absorption, sulphate soundness and Los Angles abrasion values of the carbonate rocks of Bouhti Pind (BP) and Bajar (BJ) area

S. no.	Sample no.	Specific gravity	Water absorption %	Sulphate soundness %	Los Angles abrasion value %
1	BP-1	2.67	0.60	–	–
2	BP-2	2.64	0.60	2.45	23.40
3	BP-3	2.66	0.40	2.60	29.30
4	BP-4	2.64	0.40	–	–
5	BP-5	2.63	0.60	2.95	25.25
6	BP-6	2.67	0.44	2.80	–
7	BP-7	2.65	1.00	–	21.20
8	BP-8	2.68	0.40	–	–
9	BP-9	2.69	0.20	3.50	–
Mean value		2.65	0.51	2.86	24.78
10	BJ-10	2.68	0.60	–	23.80
11	BJ-11	2.66	0.60	3.18	26.10
12	BJ-12	2.65	0.40	–	–
13	BJ-13	2.72	0.60	4.63	28.40
14	BJ-14	2.58	1.20	4.95	–
Mean value		2.65	0.68	4.25	26.10

polishing were done with 1200-micron powder to 30 μm thickness. These slides were stained with Alizarin Red-S and potassium ferricyanide to differentiate between ferron and non-ferron carbonate minerals. The thin section slides were studied under petrographic microscope employing different magnifications.

The carbonate rocks of the Bouhti Pind and Bajar area contain 92–96.3% calcite as major mineral with subordinate amounts of 0–3.8% dolomite, 2–2.1% clays, 0.7–1.0% quartz and 1.0–1.2% hematite (Fig. 2a–h). Dolomite occurs as rhombs with fine-grained calcite material (Fig. 2b). Calcite is also found as veins (Fig. 2c, h). Carbonates are present as microsparite or micrite (Fig. 2f). Some of the slides contain fossils and their broken shells (Fig. 2c). The carbonate rocks of the Bouhti Pind and Bajar are classified into packstone, wackstone and grainstone [12]. Modal mineralogical composition of the Bouhti Pind and Bajar carbonate rocks is given in Table 2.

4.2 Alkali–carbonate reactivity (ASTM C-586)

Using the specifications of ASTM C-586, 25 carbonate rock cylinders of Bouhti Pind and Bajar area having 35 mm length and 9 mm diameter were prepared. These cylinders were immersed in 1 N NaOH solution for 28 days at room temperature. Length and diameter of these carbonate rock cylinders were measured before and after 28 days immersion in the 1 N NaOH solution and recorded the change in these parameters. Results of the study are shown in Table 3.

5 Discussion

Physical and chemical characterization study was carried out to assess aggregate properties and ACR potential of carbonate rocks of the Bouhti Pind and Bajar areas. Different tests were performed to explore potential of these rocks for utilization as construction material for engineering projects. Mean specific gravity of the carbonate rocks of Bouhti Pind and Bajar area is 2.65. The specified limit of specific gravity is 2.7 for use in cement concrete and asphalt mixes [3]. This shows that mean specific gravity of carbonate rocks of both the areas lies within limits of the respective standard. Water absorption capacity of aggregates plays an important role in the strength of concrete [31]. Porous aggregates have higher water absorption values and lower strength [34]. In extreme climate, the absorbed water in aggregate is subjected to freeze–thaw process, producing cracks and damaging the concrete [41]. Mean water absorption values of carbonate rocks of the Bouhti Pind and Bajar area are 0.51% and 0.68%, respectively. ASTM C-127 allows maximum water absorption values up to 2% which means that average water absorption values of carbonate rocks of both the areas fall within limits of the standard that renders suitability of these rocks for utilization as aggregate in cement concrete.

Los Angeles abrasion values (LAAV) determines the abrasion resistance of an aggregate when used as construction material in roads [24]. Average LAAV of the Bouhti Pind and Bajar carbonate rocks are 24.78% and 26.10%, respectively. The upper limit of LAAV of aggregates for asphalt mixes, cement concrete and roads are

Fig. 2 Microphotographs **a–h** showing various features of carbonate rocks of Bouhti Pind and Bajar areas: **a** sample BP-1b indicating fossils (Foss) presence, dolomite (Dol) rhombs and calcite (Cal). **b** Sample BP-2b portrays tiny dolomite (Dol) rhombs and rhombohedral cleavage in calcite (Cal). **c** Calcite vein and broken pieces of shells in Sample BP-4b. **d, e** Samples BP-5b, BJ-10a signifies fossils and calcite presence. **f** Sparite and fossils in BJ-14a. **g, h** BJ-13c, 10b shows Lockhartia, bioclasts and calcite vein with cleavage

30%, 40% and 50%, respectively [4]. The LAAV of the carbonate rocks of both the areas are within limits of the respective standard for utilization in asphalt mixes, cement concrete and for the construction of roads.

Sulphate soundness value reflects weathering resistance of an aggregate [10]. The specified upper limits of sulphate soundness values of carbonate aggregate use in cement concrete and construction of roads are 10% and 12%, respectively [7]. Higher than standard values suggest vulnerability of rock towards weathering. While lower

values indicate soundness of rocks. Mean sulphate soundness values of the carbonate rocks of the Bouhti Pind and Bajar area are 2.86% and 4.25%, respectively. These values are lower than standard limits suggesting the soundness of these rocks and suitable for utilization in cement concrete and construction of roads.

Modal mineralogical composition of rocks plays an important role in the identification of deleterious components that can react with the alkalis of cement when used as an aggregate source in cement concrete [33,

Table 2 Modal mineralogical composition and Dunham classification of the rocks of Bauhti Pind and Bajar areas

S. no.	Sample no.	Calcite %	Dolomite %	Quartz %	Clays %	Hematite %	*Dunham classification
1	BP-1a	85	10	2	2	1	Packstone
2	BP-1b	90	6	–	2	2	Packstone
3	BP-2a	90	6	1	1	2	Packstone
4	BP-2b	75	20	1	2	2	Packstone
5	BP-3a	90	6	–	3	1	Packstone
6	BP-3b	82	14	1	3	–	Packstone
7	BP-4a	95	–	1	2	2	Packstone
8	BP-4b	97	–	–	1	2	Packstone
9	BP-5a	94	–	2	3	1	Wackstone
10	BP-5b	94	2	1	2	1	Packstone
11	BP-5c	94	–	2	3	1	Packstone
12	BP-6a	95	–	–	3	2	Wackstone
13	BP-6b	95	–	–	3	2	Wackstone
14	BP-6c	97	–	1	1	1	Wackstone
15	BP-7a	96	–	1	3	–	Packstone
16	BP-7b	86	10	2	1	1	Wackstone
17	BP-8a	90	6	2	1	1	Packstone
18	BP-8b	97	–	1	1	1	Packstone
19	BP-8c	96	–	1	2	–	Packstone
20	BP-9a	95	–	2	2	1	Wackstone
21	BP-9b	97	–	–	2	1	Packstone
22	BP-9c	97	–	–	1	2	Packstone
Mean value		92	3.8	1	2	1.2	
23	BJ-10a	96	–	1	2	1	Packstone
24	BJ-10b	97	–	2	3	–	Packstone
25	BJ-10c	96	–	–	2	2	Wackstone
26	BJ-11a	97	–	1	1	1	Wackstone
27	BJ-11b	96	–	–	2	2	Wackstone
28	BJ-11c	97	–	–	2	1	Wackstone
29	BJ-12a	98	–	–	2	–	Packstone
30	BJ-12b	95	–	2	3	–	Packstone
31	BJ-13a	97	–	–	2	1	Grainstone
32	BJ-13b	96	–	1	2	1	Grainstone
33	BJ-13c	95	–	2	3	–	Grainstone
34	BJ-14a	96	–	–	2	2	Packstone
35	BJ-14b	97	–	–	2	1	Packstone
36	BJ-14c	96	–	1	2	1	Packstone
Mean value		96.3	0	0.7	2.1	1	

46]. Petrography of the carbonate rocks of the Bajar area reveals the occurrence of 95–97% calcite, 1–3% clays, 1–2% unstrained quartz and 1–2% hematite. Carbonate rocks without dolomite are considered non-reactive with respect to ACR [13, 21]. The carbonate rocks of the Bajar area do not contain dolomite but 1–3% clays. These rocks contain 1–2% unstrained quartz which does not initiate alkali–silica reaction (ASR) in concrete. So, these rocks are innocuous and can be used as an aggregate in cement concrete. However, the Bouhti Pind carbonate rocks

contain 2–20% dolomite in addition to 75–97% calcite, 1–3% clays, 1–2% unstrained quartz and 1–2% hematite. Dolomite in association with clays is prone to alkali–carbonate reactivity (ACR) potential. Carbonate rocks possessing 40–90% dolomite and 5–25% clays cause deleterious expansion in concrete due to ACR [13, 19, 21, 46]. In Bouhti Pind, carbonate rocks dolomite and clays generally vary from 2 to 14% and 1 to 3%, respectively. These deleterious minerals are lower than threshold values to cause ACR in cement concrete and are considered innocuous. Sample

Table 3 Results of rock cylinder expansion test performed on the Bauhti Pind and Bajar carbonate rocks

S. no.	Sample no.	Length of rock cylinders mm		Diameter of the rock cylinders mm		Volume of the rock cylinders mm ³		Expansion after 28 days %	Deleterious mineral constituents % Dolomite	Clays
		Initial	After 28 days	Initial	After 28 days	Initial	After 28 days			
1	BP-1a	35.25	35.25	09.25	09.25	2367.62	2367.62	0	10	2
2	BP-1b	34.00	34.00	08.91	08.91	2118.86	2118.86	0	6	2
3	BP-2a	35.62	35.62	10.33	10.33	2949.91	2949.91	0	6	1
4	BP-2b	35.25	35.25	09.172	09.174	2327.86	2328.87	0.043	20	2
5	BP-2c	36.00	36.00	09.83	09.83	2730.73	2730.73	0	10	2
6	BP-3	34.50	34.50	09.75	09.75	2537.21	2537.21	0	10	3
7	BP-4	35.75	35.75	09.41	09.41	2484.99	2484.99	0	0	2
8	BP-5	36.00	36.00	09.75	09.75	2686.46	2686.46	0	2	3
9	BP-6a	35.50	35.50	10.00	10.00	2786.75	2786.75	0	0	2
10	BP-6b	36.00	36.00	09.08	09.08	2329.93	2329.93	0	0	3
11	BP-6c	35.50	35.50	09.17	09.17	3240.79	3240.79	0	0	2
12	BP-7a	35.00	35.00	09.83	9.83	2652.17	2652.17	0	0	3
13	BP-7b	35.25	35.25	10.16	10.16	3109.14	3109.14	0	10	1
14	BP-8a	35.75	35.75	09.41	09.41	2482.35	2482.35	0	6	2
15	BP-8b	35.75	35.75	09.67	09.67	2621.49	2621.49	0	0	1
16	BJ-9a	35.75	35.75	10.00	10.00	2806.37	2806.37	0	0	2
17	BJ-9b	35.75	35.75	09.41	09.41	2482.35	2482.35	0	0	1
18	BJ-9c	35.37	35.37	08.75	08.75	2146.17	2146.17	0	0	1
19	BJ-10	35.25	35.25	09.41	09.41	2447.63	2447.63	0	0	2
20	BJ-11a	35.00	35.00	09.33	09.33	2389.10	2389.10	0	0	2
21	BJ-11b	35.00	35.00	09.25	09.25	2348.28	2348.28	0	0	1
22	BJ-12a	35.25	35.25	09.50	09.50	2497.3	2497.33	0	0	2
23	BJ-12b	34.75	34.75	09.91	09.91	2676.29	2676.29	0	0	3
24	BJ-12c	35.75	35.75	09.50	09.50	2532.75	2532.75	0	0	1
25	BJ-13a	34.75	34.75	09.16	09.16	2288.84	2288.84	0	0	1
26	BJ-13b	35.75	35.75	09.16	09.16	2354.70	2354.70	0	0	3
27	BJ-14a	35.25	35.25	08.81	08.81	2145.29	2145.29	0	0	1
28	BJ-14b	35.00	35.00	08.50	08.50	1985.06	1985.06	0	0	2

BP-2b contains 20% dolomite along with 2% clays. Owing to lower dolomite and clays, the Bouhti Pind carbonate rocks are not prone to ACR.

The findings of petrographic analysis of the Bauhti Pind and Bajar area carbonate rocks were verified through rapid chemical method [5]. The test was performed to judge the expansion behaviour of the carbonate rock cylinders from both the area. The expansion of rock cylinder is directly linked with abundance of dolomite and clays in the rock. Owing to lack of dolomite and minor clay (1–3%) content, the carbonate rock cylinders of Bajar area did not show any expansion. Likewise, the Bouhti Pind rocks did not reveal expansion behaviour due to lower mean dolomite (3.8%) and clays (2%) contents. However, rock cylinder BP-2b which contains 20% dolomite and 2% clays showed 0.043% expansion, lower than the specified limit of 0.10% of the ASTM (C-586) standard. The results shown in Table 3

are parallel with the observations of other researchers (e.g. [13, 19, 21, 33, 46]). The study suggests that dolomite and clay contents of Bouhti Pind carbonate rocks are lower than threshold values to initiate ACR in cement concrete. Hence, the carbonate rocks of Bouhti Pind and Bajar area are innocuous with respect to ACR and can be used as aggregate sources for the engineering projects.

6 Conclusion

Physical, chemical and petrographic analysis reveal suitability of carbonate rocks of the Bouhti Pind and Bajar areas as an aggregate in cement concrete and for the construction of roads. Specific gravity, water absorption, Los Angeles abrasion and sulphate soundness values of both the areas confirm their respective specified limits

which indicate that these carbonate rocks may be used as a potential aggregate source. Petrographic study indicates the absence of dolomite in the rocks of Bajar area, while lower concentration of dolomite is found in Bouhti Pind rocks. Rock cylinder test does not show deleterious expansion in the carbonate rocks of both the areas which rule out the possibility of ACR. Hence, the carbonate rock aggregate of Bouhti Pind and Bajar areas is suitable for utilization as construction material.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author Tehseen Zafar states that there is no conflict of interest.

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