



Investigation of Carbonate Rocks of Malikhore Formation as Coarse Aggregate and Dimension Stone, SE Balochistan, Pakistan

Shahid Naseem^{1*}, Khalid Hussain¹, Bushra Shahab¹, Erum Bashir¹,
Muhammad Bilal¹ and Salma Hamza¹

¹Department of Geology, University of Karachi, Karachi 75270, Pakistan.

Authors' contributions

This work was carried out in collaboration between all authors. Author SN designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors KH, BS, EB managed the analyses of the study and literature searches. Authors MB and SH studied thin sections of the rocks. All authors read and approved the final manuscript.

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ABSTRACT

Properties of coarse aggregate of carbonate rocks of Malikhore Formation of Jurassic age of districts Lasbela and Khuzdar, SE Balochistan were investigated. Bulk specific gravity (SSD), water absorption, sieve analysis, Los Angeles abrasion test, unconfined compressive strength, soundness, silica alkali reactivity, clay lump and friable particles, loose and rodded density, flakiness and elongation indices of coarse aggregate were evaluated for building and road material. Nearly all the samples were found within the specified limits of ASTM specifications and are appropriate material for concrete, asphalt and suitable as dimension stone. The variation in color and texture of carbonate rocks of Malikhore Formation has good demand from the local and foreign markets as dimension stones.

Keywords: Coarse aggregate; malikhore formation; dimension stone; Balochistan.

*Corresponding author: E-mail: sngao@yahoo.com;

1. INTRODUCTION

Karachi is a big growing city with large population [1]. As the population increases in any area, lots of civil structures such as buildings, offices, roads etc. are needed to fulfill the socio-economic necessities of the people. For this purpose, vast amount of building material in form of aggregates and dimension stones are required. Within the Karachi city, a number of mega projects such as high-rise buildings, shopping malls, flyover and underground passes are under construction. Network of highways, industrial estates, mega cities, small dams etc. are also planned in the Lasbela and Khuzdar districts. The adjoining mountain ranges are the main sources of acquiring most of the building materials in Karachi and Balochistan. The area of study is situated in north of Karachi city (Fig. 1).

Civil engineers, architects and geologists are an integral part for construction and designing beautiful and durable buildings, bridges, highways and dams. Civil engineers assess site characterization and geotechnical design of modern and mega structures [2]. Material engineers select appropriate earth materials (aggregate, sand, silt, clay etc.) and evaluate their properties as per American Society for Testing and Materials (ASTM) standards [3]. A common understanding of the relationship between geologic origin and geotechnical

properties is essential to assure the best product quality. Millogo et al. [4] emphasize to study geotechnical and mechanical properties of aggregates and the structure for durable construction.

Keeping in view the above considerations, the present research work was undertaken to evaluate the aggregate and dimension stone characteristics of carbonate rocks of Malikhore Formation in the Lasbela regions. This is very first attempt to carry out this sort of work in the area and is expected to open new research endeavors in future. This work may also draw attention local and foreign builder's community in the selection of good quality building material of world standards and can play its due role in developing the country and boosting the economy.

2. GEOLOGICAL SETTING

Geologically, study area is a part of the Western Fold Belt (WFB) which is outcome of collision between Indian and Eurasian plates. The WFB represents the fore land fold and thrust belt along the western margin of the Indian Plate [5]. The area is located in the west of the Pab and Mor ranges. In Lasbela District, Bela Ophiolite is sandwiched between the two ranges. The area is comprised of Jurassic to Miocene sedimentary rocks [6].

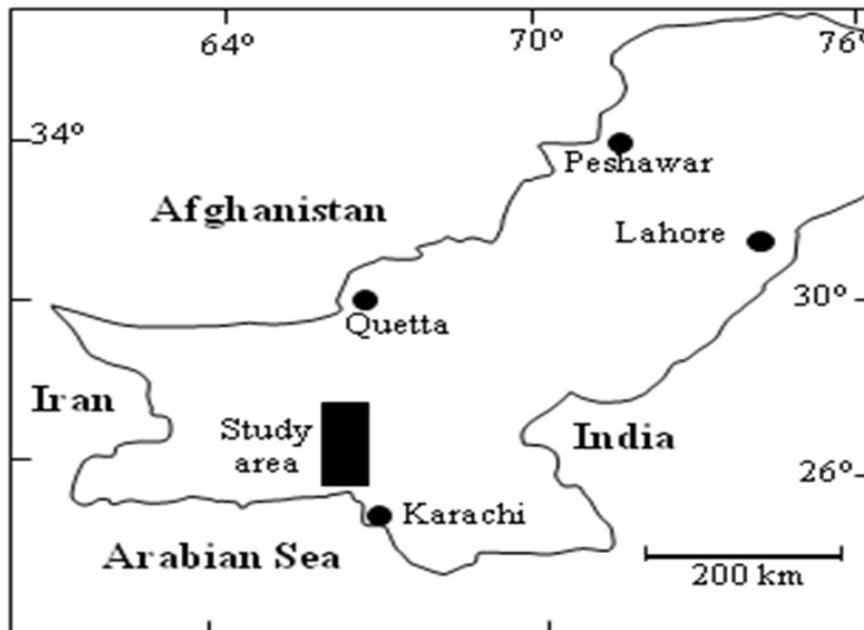


Fig. 1. Map displays the location of the study area within Pakistan

The Jurassic clastic and carbonate rocks of Ferozabad Group are extensively exposed in the Mor Range (Fig. 2). They are shelf deposits which are formed as a result of breakup of Pangaea [7]. The group is comprised of Kharrari, Malikhore and Anjira formations [8]. Fatmi et al. [9], introduced term Malikhore Formation in place of Lorlai Member of Shirinab Formation. It is derived from the Malikhore Village, west of Khuzdar. Major lithology of the formation is hard, compact, crystalline limestone deposited in platform conditions with thin partings of subordinate shale [10]. Repetition of strata with pelletal, oolitic, conquinoid and micritic textures is an important character of formation [11]. Formation shows variation in thickness; at typical locality it is 387 m thick [12]. The age of formation is assigned as Early Jurassic [13,14].

In the Pab Range, sedimentary rocks of Cretaceous age are widely distributed. Sembar, Goru, Parh, Moghalkot and Pab formations [6] including Cretaceous sedimentary rocks constitute Parh Group. In the upper part of the study area, Nari Formation of Tertiary age is well exposed (Fig. 2).

Exposures of Malikhore Formation are found throughout study area. It is well exposed at east of Bela, Asandro and Jurri localities. The

hardness and compact nature of formation makes it suitable for construction material and presence of variable texture also makes it more appropriate for embellishment purpose.

3. MATERIALS AND METHODS

To study the properties of aggregates of Malikhore Formation, samples were collected from Lasbela and Khuzdar districts of Balochistan. Approximately 40 kg of fresh piece of rock samples were collected as per ASTM [15] specification. Specific standard methods of ASTM were adopted for the investigation of properties like bulk saturated surface dry (SSD), water absorption, sieve analysis, Los Angeles abrasion test, unconfined compressive strength, soundness, silica alkali reactivity, clay lump and friable particles, loose and rodded density, flakiness and elongation indices. Flakiness and elongation Index of an aggregate can be estimated by measuring ratios between length, width and thickness. The Flakiness index is measured with the help of sieve while Elongation Index is assessed with the help of caliper devise. Thin sections were prepared by using Buehler Petro-thin device and were studied using Laborlus Pols microscope and photographed on Leica Microsystem, (DFC 280).

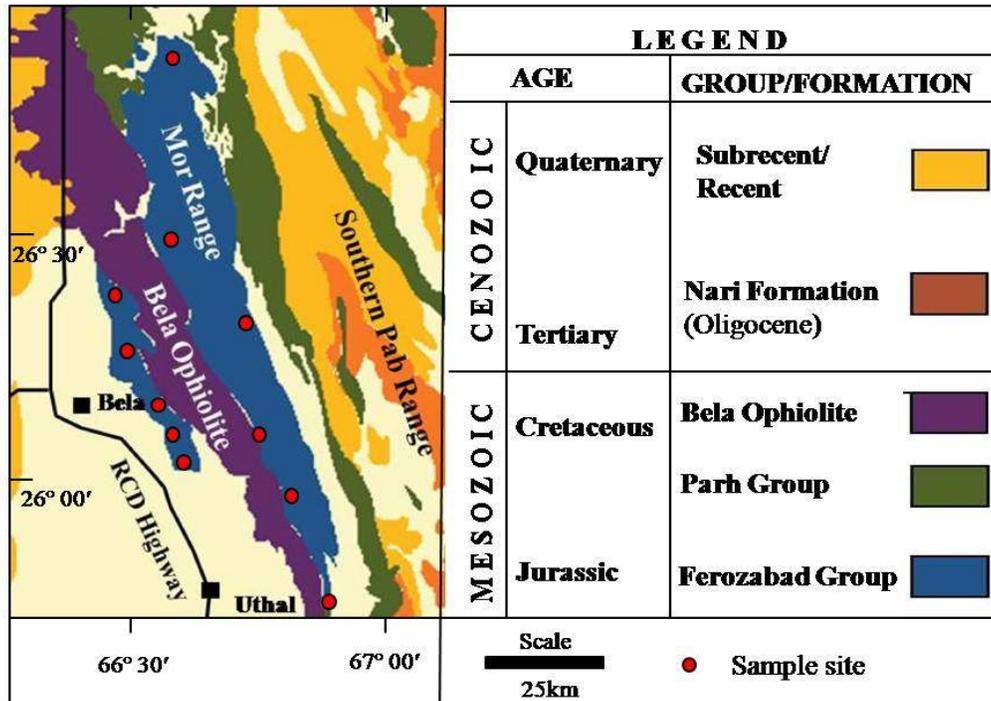


Fig. 2. Geological map of study area showing location of sample sites

4. RESULTS AND DISCUSSION

4.1 Bulk Saturated Surface Dry (SSD) Specific Gravity

The specific gravity (SSD) of an aggregate is measured according to ASTM [16] specification. In this procedure, aggregate has been soaked and left overnight so water is absorbed into its pore spaces; then excess, free surface moisture has been removed so that the particles are still saturated, but surface of the particles is essentially dry. This is SSD specific gravity.

$$\text{Bulk specific gravity, SSD} = A / (A - B)$$

A = mass of saturated surface dry aggregate
 B = weight of aggregate submerge in water

Bulk gravity (SSD) of sample collected is presented (Table 1) and shows minor difference in minimum, average and maximum values (Fig. 3). All collected samples exhibit the SSD range of normal weight aggregate.

4.2 Water Absorption

The content of absorbed water in the samples of study area is low (Table 1), probably due to less porous nature of limestone. All the samples have water absorption within 2% specified limits [16,17]. Samples of Malikhore Formation have low water absorption capacity with little variation (Fig. 3), because all fractures and pores are filled-up by calcite. The assumption also gets support from the negative correlation matrix ($r = -0.146$) between the SSD and water absorption.

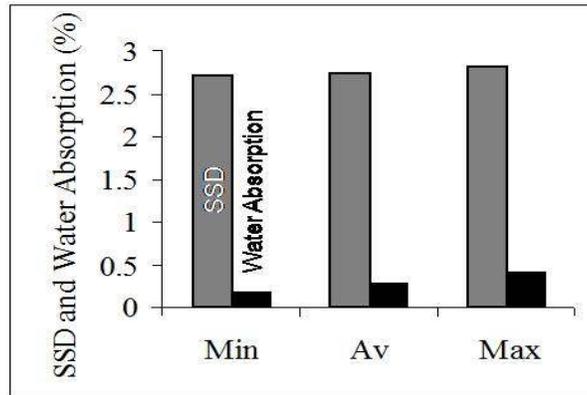


Fig. 3. Minimum, average and maximum values of SSD and water absorption of Malikhore Formation

Table 1. Physical and mechanical properties carbonate rocks of Malikhore Formation, Lasbela and Khuzdar areas, Balochistan.

	SSD	Water Ab.%	Los angles	Soundness	Clay lumps	Flakiness	Elongation
M1	2.72	0.42	24	0.9	0.22	5.5	4.2
M2	2.73	0.31	26	1.2	0.23	6.3	5.2
M3	2.72	0.28	28	1.2	0.24	7.5	6.1
M4	2.72	0.17	23	1.4	0.12	7.9	5.6
M5	2.77	0.24	25	1.3	0.32	8.8	9.2
M6	2.71	0.19	21	0.9	0.41	5.7	5.9
M7	2.81	0.25	24	1.7	0.32	9.3	6.1
M8	2.75	0.28	23	1.7	0.31	5.3	6.7
M9	2.71	0.34	21	1.3	0.3	5.9	6.3
M10	2.74	0.31	22	1.3	0.25	6.2	4.8
M11	2.76	0.29	21	1.3	0.21	6.8	4.7
Min	2.71	0.17	21	0.9	0.12	5.3	4.2
Max	2.81	0.42	28	1.7	0.41	9.3	9.2
Av.	2.74	0.28	23.45	1.29	0.26	6.83	5.89
ASTM	2.70	<4%	<50%	<12%	<3%	<15%	<15%

4.3 Sieve Analysis

In material science, distribution of grain size is important, both in the concrete and asphalt. In Portland cement and concrete (PCC), the proper gradation will help to assess workability, strength, durability and shrinkage; while it also facilitates to evaluate stiffness permeability, moisture susceptibility fractional and fatigue resistance in the hot mix design [18].

Gradation curve is one of the simplest ways to demonstrate variation in the size of aggregate. Fuller and Thompson's [19] equation is used, in which size of the sieve is raised to the nth power (usually taken as 0.45) and convenient for determining the maximum density line and adjusting gradation [18]. In the graph, size of the aggregate is plotted on x-axis in descending order; while passing percent is plotted on y-axis. A diagonal straight line is created from zero to the maximum size of the aggregate (Fig. 4). This 0.45 power curve of gradations provides a concept to appraise the distribution of different sized aggregate. Based on variation in the size of aggregate, five different types of size distribution curves are familiar, namely, dense graded, gap-graded, uniformly graded, well graded and open graded (Fig. 4). The average grain size curve of Malikhore Formation illustrate that coarse fraction has affinity with uniform gradation while finer materials show resemblance with open gradation. In spite of the fact, the gradation curve

is within the upper and lower limit of coarse aggregate (Fig. 4). The size is good enough for durable and high strength concrete, because it requires less cement for binding. Similarly, the size is convenient to bear freeze-thaw damage.

4.4 Los Angeles Abrasion

Los Angeles (LA) abrasion test provides a clear perception for abrasion, hardness, degradation and disintegration of the aggregate. Estimate of LA abrasion is essentially required to judge the firmness of either the concrete or asphalt to bear wear and tear right from their manufacturing and during their utilization for long time. In the present study, ASTM [20] procedure is applied for estimation of LA abrasion. A total of 11 LA abrasion tests were run. Triplicate samples, retained of 19 and 9.5mm sieves (5 kg) were used for the measurement and average is listed in Table 1. Mass of the coarser aggregate (>1.7 mm) is noted, after the specified 500 revolutions of the drum, to calculate exact mass of aggregate. Loss percent values of the samples of study area are ranged between 21 to 28% with average 23.45% (Table 1). The LA values of present study, lower than of maximum permissible limit (<50%) signifies that the values are good enough not only for concrete cement to control mixture problems but also it will minimize the production of excessive fine particles during working, which would ultimately reduce the risk of possible environmental problems.

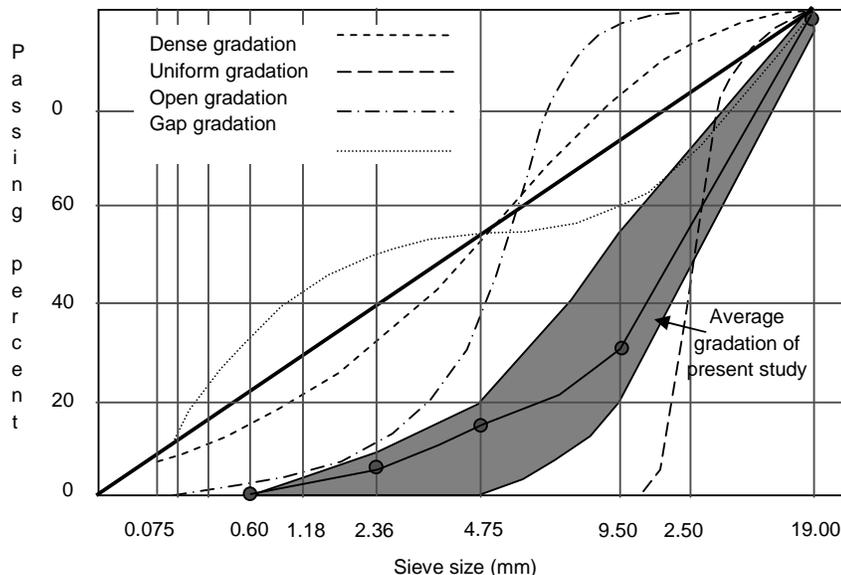


Fig. 4. Types of gradation curves and curve of the study area, based on average grain size. Shaded area specifies upper and lower limits of coarse aggregate

4.5 Unconfined Compressive Strength

Unconfined compressive strength (UCS) of construction material is probably the most important index properties for the evaluation of mechanical behavior of rocks [21]. The UCS provides a clear perception regarding the selection of material for appropriate civil structure. UCS is also used to calculate the energy required to cut the sample [22,23]. Furthermore, it helps in selection of appropriate excavation technique. In the present study, sample M3 was cored to measure UCS as per ASTM [24] specifications and was noted 6,179 psi. The moderate value of UCS is mainly due to presence of calcite filled veins. The strength of rock decreases in the presence of joints and veins [25].

4.6 Soundness (NaSO₄ method)

Sulphate soundness is commonly employed to measure the freezing and thawing durability of aggregates. Freezing and thawing characters of an aggregate is assessed by repeatedly submerging the aggregate in a sulphate solution and oven drying. In the present work, NaSO₄ soundness method is opted for the studies, as per ASTM [26] specifications. The result of soundness is given in Table 1. It shows minimum value 0.9%, while 1.7% is the maximum. The average is found to be 1.29. The present study indicates that the all samples are good, and have low soundness compared to [26] recommended value of 12%.

4.7 Alkali Silica Reactivity (ASR)

The ASR is one of the most familiar harmful incidents in concrete. The ASR is a chemical reaction that occurs between the reactive SiO₂, present in the aggregate and the alkalis (K₂O +Na₂O), common in the Portland cement. During the hydration of cement, Ca ions are easily integrated in the hydrating concrete but K and Na remain in fluid, which eventually increase the pH >13. The samples of present study are relatively pure limestone and apparently they are free from any reactive silica. In the presence of high amount of Ca ions, Na and K are not able to compete with Ca because of slow rate of migration, thus the chances of gel swelling is minimum and the resultant concrete is free from cracking [27]. Similarly, high Ca obstructs diffusion of silicate ions from the reactive grains [28]. Potential reactivity of the aggregate was assessed; using ASTM method [29] and is presented in graph (Fig. 5). Graph is constructed by plotting silica (Sc) versus reactivity (Rc). Area of the graph is divided into two portions, plots in the left hand side show innocuous material for concrete while right side plots belong to deleterious materials. The division is not straight but a curved line demarcates boundary between them (Fig. 5). On the basis of silica and reactivity, deleterious aggregates are further divided into potentially deleterious aggregates (top) and less deleterious material (below). All the samples plotted within the domain of innocuous material with low reactivity (Fig. 5).

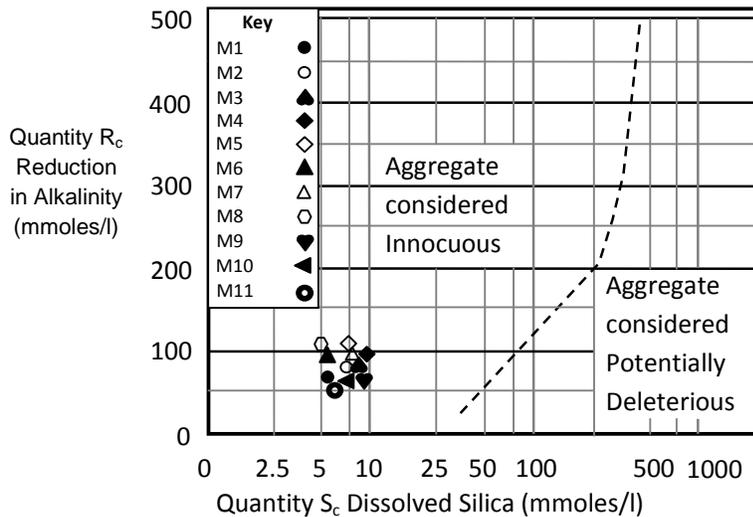


Fig. 5. Sc versus Rc plot of carbonate rocks of Malikhore Formation; Adopted after ASTM [29]

4.8 Clay Lumps and Friable Particles

The clay lumps and friable particles is defined as any soft friable or clay like material, which can easily be removed when squeezed between the thumb and forefinger or will disintegrate into small pieces when aggregate is immersed in water for a short period. Coating clay which sticks on the surface of aggregate will hinder the bonding between cement and aggregate. If the quantity of clay in aggregate exceeds the maximum allowable limit (1.5%), it will harmfully influence durability and strength of concrete. Excessive clay lumps present in aggregate interfere with the bonding between asphalt and aggregate. This will cause stripping and pop-outs in the pavement [30].

The method follows the procedure of ASTM [31], for determination of clay lumps and friable particles in aggregate. The carbonate rocks of Malikhore Formation are relatively pure and clays are present in minor quantity (average 0.26%). Results of clay lumps and friable particles of current study given in Table 1 shows low amount of fine particles, thus it is good for asphalt and concrete.

4.9 Loose/Rodded Density

The loose and rodded density of an aggregate is another important property that depends mainly on specific gravity. The term loose unit density refers to weight of an oven-dry aggregate required to fill a container of known volume without any external force to compress the mass. It is the measurement of aggregate volume with the volume of void spaces [32].

The average bulk density of aggregate, commonly used in normal weight concrete ranges from 1.2 to 1.75 g/cm³. Values of the loose density mainly rely on density of the aggregate, surface texture, size and shape of the particles. Aggregates lacking predominance of one size will usually have a higher bulk density in contrast to those having preponderance of one size particles present [33]. High amount of flaky and angular shape particles reduces the bulk density of material.

Method of ASTM [34] is adopted for present study and calculated bulk loose and rodded densities (Fig. 6). Bulk loose density of the samples of study area is in the range of 1.41-1.68 g/cm³, while rodded density varies between

1.64 and 1.89 g/cm³. The mutual relation in form of correlation matrix between loose and rodded densities is noted good ($r = 0.71$). The plots of bulk loose and rodded densities show good relationship, however minor variation in the densities is mainly due to the shape and density of the aggregate itself (Fig. 6). Well compacted aggregates are stronger and require less amount of cement in the concrete. In the construction of road, nearly 110% rodded unit weight is generally considered to be the upper limit of coarse aggregate [32]. The samples of the study area are suitable material in this regard, because the average compaction is 115%.

4.10 Flakiness and Elongation Index

Shape of the aggregate is very crucial in the cement concrete. Proper shaped (equant) aggregates are needed for easy workability, deformation resistance and proper compaction. However, quantity and proportion of different shaped particles largely relies on the nature of civil work [35]. Poor strength of concrete is obtained in the presence of high amount of flat and elongated particles in the aggregate. Both of them are unable to bear heavy load and fracture more easily than the other aggregate particles [36]. Such flat and elongated particles also require more water for binding, which ultimately influence the mechanical characteristics of concrete. Furthermore, aggregate with high proportions of flat and elongated particles may also cause segregation in the fresh mix, which leads to low durability and strength of the concrete. In the pavement structure, proportion of aggregates is nearly 90-95% of the total volume of hot-mix asphalt (HMA). For this reason, shape of the aggregates; appreciably affect the overall quality and durability of the pavement [37]. The high quality of HMA mixture largely depends upon the presence of rough and angular aggregates [38]. Cubical shaped aggregates are most advantageous in HMA, while flat and elongated particles considered adverse because they tend to break during compaction and under heavy traffic [39].

The samples of the study area show an average of 5.89% elongated and 6.83% flat particles (Table 1) and are within the specified limit of 15%. Percentage of flat and elongated particles in the sample largely depends upon the composition, nature of bedding, compactness, hardness and influence of tectonism prevailed in the area [40] and also on way of crushing.

4.11 Petrography

Petrography is the systematic study of rock specimens in thin-section. It is an integral part of material science, widely used to assess and classify aggregate for civil works, under ASTM [41] specifications. The petrographic study plays a supportive role in order to assess the results and interpretation of other tests [42]. It is a very essential parameter to infer about the composition of an aggregate. The study can be used to identify weak and reactive minerals, known to be linked with poor performance of aggregate [43]. During the petrographic study, examination of weathered and altered particles of the aggregate is also intended. Joints, cracks and other fracture are noticed during petrographical observations on microscopic level.

4.11.1 Sample M3

The thin section study revealed it as a micritic limestone. Calcispheres are also common. Patches of hematite are common in the entire

body. A number of micro veins are also common, which are filled with pure sparry calcite (Fig. 7a). At places, stylolitic structure is seen, reflecting Jurassic tectonism in the area. Fossils are not present.

4.11.2 Sample M6

The limestone is grey in colour and fine crystalline. Rounded hematitic bodies are also visible in the groundmass of the thin section. Few fossils and their fragments are visible. The thin section area is full of fractures, which are healed up by hematite (Fig. 7b). Some sort of rock cleavage is also developed at microscopic level indicating complexity in the structure of the rocks.

4.11.3 Sample M7

It is a fine crystalline (micritic) and relatively pure limestone. Numerous laths and cavity-filled hematite are visible. The sample has several criss-cross rhombohedral calcite filled veins (Fig. 7c).

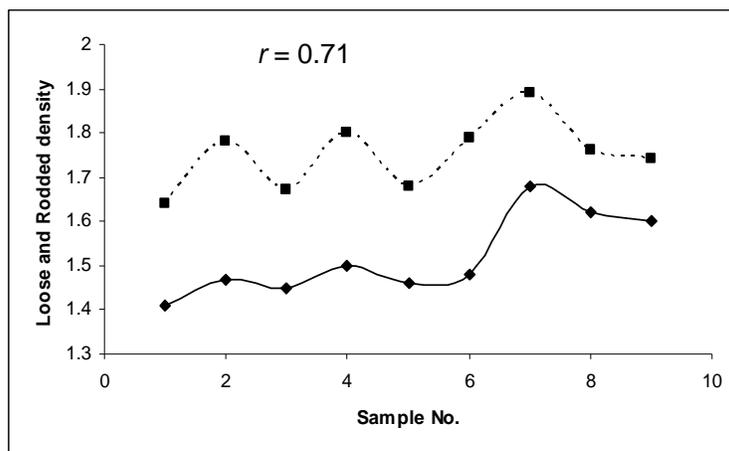


Fig. 6. Relationship between loose and rodded density of corresponding samples

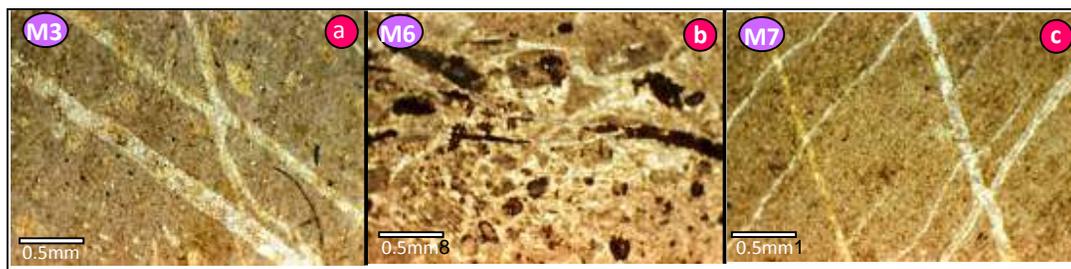


Fig. 7. Photomicrographs of carbonate rocks of Malikhore Formation. Sample numbers are marked on top left



Fig. 8. Block and tiles of the carbonate rocks of Malikhore Formation

5. DIMENSION STONE

The limestones of Malikhore Formation are famous for their durability and archetypal appearance. Its versatility in colour and texture makes it suitable for floor tiles, facing stone and window sills. In the study area, it is mined from different localities of the Lasbela and Khuzdar districts. Majority of extracted stones are processed in Marble City Gadani, Balochistan, where 130 processing units are in working. Monolama and diamond saws are used to cut irregular blocks into large slabs (Fig. 8a, above). These blocks are mainly exported to China and Saudi Arabia. Slabs are further cut into demanded sizes by small cutters into tiles, tabletops and kitchen tops etc. (Fig. 8b, above).

A single unit in the Marble City is capable to produce annually 9,600 tons dimension stone. Presently 130 units are fully operative in the Marble City. Per ton expenses include, mining US\$ 42, logistics US\$ 16, and cutting and other require US\$ 8.5. The net expenditure on one ton dimension stone is US\$ 66.5. These blocks are being exported at a rate of 120-130 US\$ per ton. It is estimated that export of approximately 100 US million \$ per annum from Marble City, Gadani was expected.

6. CONCLUSION

Malikhore Formation of Jurassic age is exposed in the Lasbela and Khuzdar areas, Balochistan. These rocks are widely used to fulfill the local demand for building and road constructions as well as dimension stones which have good export potential abroad.

The average specific gravity (SSD) of carbonates of Malikhore Formation is 2.74, which classified it

as normal-weight aggregate. It also has low water absorption capacity (av. 0.28%). The distribution of different sizes of the crushed material showed that the average gradation curve is within the ASTM specification and can be classified as open-dense graded. The size is good enough for durable and high strength concrete and convenient to bear freeze-thaw damages. The Los Angeles abrasion loss (23%) and unconfined compressive strength (6,179psi) designate it as suitable material to bear load. The mean value of soundness test of present study is 1.29, much lower than ASTM recommended value (12%).

The carbonates of Malikhore Formation have low estimated silica (Sc) and reactivity (Rc) potential and are plotted within the domain of innocuous material. It is safe to use it for cement concrete and asphalt with no hazard of expansion. Clay lumps and friable particles are very low (av. 0.26%). Rodded density of aggregate indicates compactness nearly 115%. The amount of flat and elongated particles is 6.83 and 5.89% respectively. The petrographic study revealed micrite/biomictite type of texture with numerous veins filled with calcite and iron oxides. All the above properties are within the ASTM specified limits and mark it as a suitable material for concrete, asphalt and dimension stones.

Tiles and blocks of carbonates of Malikhore Formation have good demand in the local and foreign markets as dimension stone. This sector approximately earns US\$ 100 million per annum from the export.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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