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ARTICLE

Assessment of Bholari River Sand for Its Geotechnical Characterization as Fine Aggregate

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ABSTRACT

Present study is aimed at assessment of Bholari river sand for its geotechnical characterization and suitability as fine aggregate which is being quarried in Jamshoro district, Sindh, Pakistan. For this purpose, sand samples (n=11) were collected from quarry sites and main river channel. Physical properties reveal that Bholari sand is mainly coarse to fine in size (0.2 mm-5 mm). Average values of fineness modulus, specific gravity, bulk density and void content of collected samples are 2.58, 2.56, 1659.90 kg/m^3 and 35.12% respectively which varied within the corresponding permissible ranges of ACI (American Concrete Institute). Carbonate content of about 57.59% is also in agreement with corresponding range for fine aggregate. Petrographic examination revealed that Bholari River sand mainly comprises of quartz and rock fragments with subordinate limestone fragments. As per classification of Dott (1964), Bholari sand is lithic arenite where quartz (50%) occurs as main mineral followed by rock fragments (30%), feldspars (15%) and other opaque minerals (5%). Texturally, the sediments are angular (77%) to sub-round (33%). All these physical properties lie within the range set by National Highway Authority (NHA) and American Standard of Testing Material (ASTM). It is concluded that Bholari River sand is suitable for use in concrete mixed with cement and asphalt.

1. Introduction

The variety of geomaterials encountered in engineering problems is almost limitless, ranging from rigid, dense, large pieces of rock, through gravel, sand, silt, and clay to organic deposits of soft, compressible peat [1]. Natural aggregate is one of the most abundant materials occurring on the earth's surface and used as a construction material for many years [2]. Construction material plays a vital role in development of infrastructures for the nation [3]. Aggregates are widely used in concrete, foundations, mortar, grout, steel-reinforced beams, flooring and retaining walls as well as a filler material [4-8]. Characterization of river sand and weathering products of sandstone have been widely reported for the potential use of glass making [9].

Aggregates have been divided into fine and coarse based

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on grain size. Sand should have a proper gradation of particles which ranges between 0.075 mm to 4.75 mm to be used as construction material. Aggregate can be divided into 3 main types, a) natural primary aggregate which includes sedimentary, igneous, and metamorphic rocks, b) secondary aggregate, which is derived as a by-product from industrial processes, and c) recycled aggregate, which is recovered from past construction material.

Sand is the major component in concrete mixes. The main natural and cheapest resource of fine aggregate is river sand [10]. When fine particles are in proportion, the sand will have fewer voids and the cement quantity required will be less [11]. Sand from natural gravel deposits or crushed rocks is a suitable material used as a fine aggregate in concrete production. It is used with coarse aggregates to produce structural concrete and also used alone with cement for mortars and plastering works. It is also economical as it is abundant near most construction works [12]. The quality of sand as fine aggregate can be characterized by several geological factors such as the grade of sand, carbonate content, silt, clay quantity, and organic impurities [11]. Genetically, sand is subdivided into 3 types based on grain size i.e. fine (least used), medium, and coarse grain sand which is mostly used for construction purposes.

About one third of the total volume of concrete aggregates is filled by the fine aggregate, where the space between coarse aggregates is filled by it. The quality and quantity of fine aggregates have a direct effect on the behavior of both fresh and hardened concrete [13]. Fine aggregate is used to provide the fineness and cohesion in concrete.

Pakistan is a country with many rivers flowing through it, bringing sediments to form the northern part from where they originate. So, the river sand is most commonly found and is available throughout the country, making it the most common aggregate used in the construction industry. Quarrying is the process through which aggregate is produced in Pakistan. Sieving is performed after quarrying to separate fine aggregate from coarse aggregate and unwanted gravels and rubbles for multiple uses.

Aggregate is mainly used by the construction industry in Pakistan. Precision in the specification of aggregates is more important. The quality of concrete depends upon the quality of aggregate used. The characterization of fine aggregate depends upon the physical properties that include gradation, specific gravity, and volume change. For the use of aggregates in construction, the first step is to understand the geology of the desired area, processes used in production, and the method of the references. Deleterious material present in the aggregate is harmful for use in construction and other purposes as it can react with the concrete and could deteriorate it.

China-Pakistan Economic Corridor (CPEC) has brought a noteworthy exponential increase in the construction sector of Pakistan. Karachi city which is mainly influenced by CPEC and is the economic hub of Pakistan. Various mega projects of construction are in progress in Karachi city. These megaprojects that are changing the face of the country need huge quantity of raw material in the form of aggregate for construction. However, lamentably, there is a shortage of the aggregates and a dire need to explore the aggregate resources. For sustainable construction activity in Karachi city, a huge quantity of aggregate is being provided by the Bholari river sand in Jamshoro district, Sindh. A number of quarry plants are working in Nooriabad area. Hyderabad, Jamshoro, and adjoining areas are also being supplied by the same aggregate. Despite considering Bholari River sand as an important source of fine aggregate, limited study has been carried out on such aggregate deposits. Hence, present study is aimed at assessment of Bholari river sand for its geotechnical characterization and suitability as fine aggregate.

Study Area

Study area is Bholari River in Sindh which is also called "Baran Nai". Total length of the river is about 160 km (99.2 miles). It originates from Kirthar Range near Goth Jam Nida, Las Bela District, Baluchistan and goes all the way through Thano Bulla Khan and ends up making a fan shaped deposit near Kotri and Indus River and flows in low lying area between Kirthar Ranges on the west and Hyderabad High on the east (Figure 1). Bholari River flow along the transact of the various exposed lithology that include Kirthar Formation, Laki and Tiyon Formation, Nari Formation, Gaj Formation and Manchar Formation of Eocene, Oligocene, Miocene and Pliocene respectively which are also exposed in Thano Bulla Khan and adjacent areas.

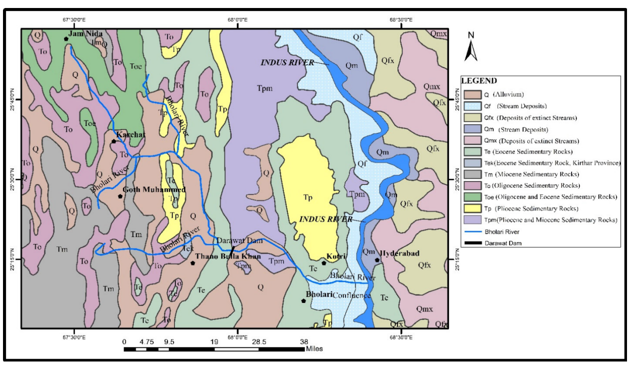

Figure 1. Geological map of study area.

Blanford used name "Kirthar" after the Kirthar Range to describe Eocene strata between his "Ranikot Group" and "Nari" in western Sindh [14]. The Kirthar Formation is defined as predominantly limestone with some shale and marl. The limestone is light grey, cream colored or chalky white, and weathering in grey, brown or cream colors. It is thick-bedded to massive, in places nodular, and occasionally contains algal and coralline structures. The shale is olive, orange yellow, grey, calcareous, soft and earthy [15].

Laki group is sub divided into two major formations that includes Laki Formation and Tiyon Formation. Laki Formation is sub-divided into Sohnari and Chat member. The Sohnari member is also known as Basal Laki laterite which includes laterite clay, shale and sandstone with interbeds of limestone. The Chat member is also sub-divided into Meting limestone, Shale and Laki limestone and Shale units [15].

The Tiyon Formation consists of shale with subordinate marl and limestone. Shale is greenish grey, brown, yellowish grey, soft, crumbling, calcareous, gypsiferous, and fossiliferous [15].

The Nari Formation, derived from the Nari River in the Kirthar Range, was introduced by Blanford [14]. Nari Formation consists of sandstone, shale and subordinate limestone. The lower part of the formation is predominantly composed of crystalline limestone which is white to grey on color. Thin stringer of dark shale and of thin bedded and fine-grained brown sandstone are also present. The upper part of the Nari Formation consists predominantly of sandstone, which is greenish grey, grey brown and white coloured, fine to coarse grained often gritty and calcareous with subordinate shale, sandstone and varicolored claystone. Beds of conglomerate and ironstone are present either at the base or in the upper part [15].

Whereas, Gaj Formation was also introduced by Blanford for a sequence of shale and sandstone with subordinate limestone [14]. The Gaj Formation consists of shale with subordinate sandstone and limestone. The shale is variegated greenish grey and gypsiferous. The sandstone is brown greenish grey, calcareous, ferruginous and cross-bedded. The limestone is brown or yellowish white argillaceous and fossiliferous. At some places minor conglomerate beds containing pebbles, separately derived from the Nari Formation are also present. In Karachi region, the Nari Formation consists predominantly of white or yellowish brown soft, crumbly to hard sandstone and cream colored or pinkish white argillaceous limestone [15].

Similarly, Manchar Formation, first described by Blanford, is widely exposed around Lake Manchar, along the foothills of the Kirthar Range, and in substantial area between Kirthar Range and Indus River [14]. The term "Siwalik" has also been used for the Manchar Formation in the southern part of the Kirthar province [15-18].

The Manchar Formation is composed of alternating sandstone and siltstone, with thin beds of conglomerate that increase in thickness and frequency up-ward in the section. The sandstones are gray, soft, and moderately fine grained, and composed of quartz, feldspar, and hornblende. The silt beds are sandy, and commonly yellow and red in color. The conglomerates chiefly contain clasts of soft gray sandstone and nodules of silt [18].

The study area consists of a valley between Laki Range and Hyderabad High and consists of major anticlinal and synclinal structures in the surrounding area due to extreme tectonic deformation. Surjan, Jhimphir and Lakhni are the three major faults that occur in the surrounding of study area. North-South trending Surjan fault is present in the west of study area and is intersected at the south by the North-West trending Jhimphir faults that is present southward of the study area. In the north of study area, north-south trending Lakhni fault occurs [18].

2. Materials and Methods

Fine aggregate samples (n=11) were collected from various quarry sites (locally termed as Reti Dikkas) operating around Bholari River, Jamshoro District. Sampling was carried out in compliance with ASTM D-75 from stockpiles. Fine aggregates were characterized for (a) physical properties and (b) mechanical properties.

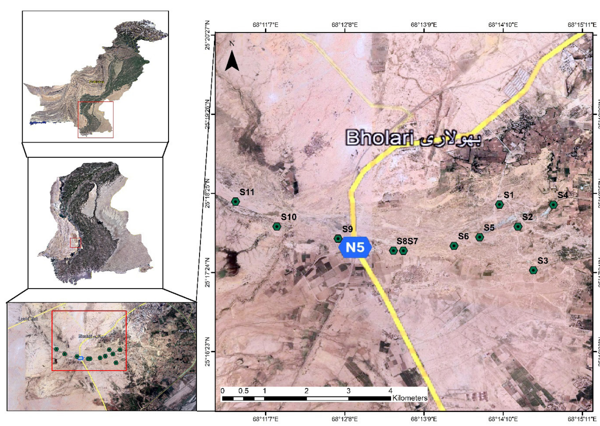

Figure 2. Samples location map.

Physical Properties of Aggregate

Following tests were performed for the examination of aggregate physical properties:

Grain Size Analysis/Fineness Modulus (ASTM C136)

Collected sand samples were analyzed for granulometric distribution by using dry sieving technique as prescribed by Folk [19]. US standard set of sieves having screens of 4, 8, 16, 30, 50, 100 and 200 mesh were used. By using sieve results data, graph for cumulative frequency and grain size frequency histogram was plotted.

Specific Gravity and Water Absorption (ASTM C128)

The specific gravity was calculated for the Oven Dried (OD) fine aggregate. The apparatuses needed for this test are oven, pycnometer and weighing balance. Following is the formulae of calculating OD specific gravity value:

$$\text{Specific Gravity (OD)} = A/(B-C)$$

where,

A=Oven dry mass of sample in air

B=Saturated surface dry mass of sample in air

C= Saturated surface dry sample apparent mass in water

Bulk Density (ASTM C-29)

Bulk density and void content were determined by using ASTM C-29 method. Bulk density was determined in loose and compacted stages. Compacted bulk density was examined by rodding method.

Bulk density was calculated by using following formula:

$$M = (G-T)/V$$

M= Aggregate bulk density (kg/m^3)

G = Mass of the aggregate including measure (kg)

T = Mass of measure (kg)

V = Volume of measure (m^3)

The formula of void content is as follows:

$$\text{Void Content (\%)} = ([(S\times W)-M] \times 100)/((S\times W))$$

where,

M = Bulk density of the aggregate (kg/m^3)

S = Bulk specific gravity (dry basis)

W = Density of water (998 kg/m^3)

Volume of measure was calculated by using following formula:

$$V = (W-M)/D$$

where,

V = Volume of measure (m^3)

W = Mass of the water, plate glass, and measure (kg)

M = Mass of the plate glass and measure (kg)

D = Density of the water for the measured temperature (kg/m^3)

Mechanical Properties

For the examination of aggregate mechanical properties following tests are carried out:

Carbonate Content and Insoluble Residue (ASTM D-3042)

The carbonate content of sand was determined in compliance with the ASTM D-3042. Carbon Dioxide gas is emitted during this process which indicates the presence of carbonate content. It is performed by treating 1 g of pulverized and mesh No 200 (75 µm) passed sample in conc. Hydrochloric Acid (HCl) resulting in the complete dissolving of carbonate content leaving all the insoluble residue which is then filtered out and weighted.

Petrographic Examination (ASTM C 295)

This examination of sediments was carried out to determine any argillaceous sediment, fossils or chert as deleterious material. It was also performed to observe the particle morphology, grain size and shape. Semi quantitative study of the samples was also carried out to determine the angularity of sediments and surface texture roughness.

3. Results

All representative samples (n=20) were tested according to reference standard given by ASTM and the results have been summarized in Table 1.

Table 1. Aggregate samples testing results.

Reti Dikka	Sample #	Fineness Modulus	Specific Gravity	Bulk Density (kg/m3)	Void Content (%)	Carbonate Content (%)	Insoluble Residue (IR %)	Angular grains (%)	Surface Texture Roughness (%)
Abandoned Reti Dikka (due to rain)	1	2.92	2.63	1633.85	37.75	75.10	24.90	80.00	70.00
River Channel	2	2.94	2.53	1655.92	34.42	76.40	23.60	75.00	80.00
Shah Jilani Reti Dikka	3	2.64	2.66	1722.16	35.13	56.90	43.10	80.00	60.00
Pir Shoukat Hussain Reti Dikka	4	2.20	2.48	1624.73	34.46	43.60	56.40	80.00	85.00
River Channel	5	2.55	2.54	1648.84	34.95	73.50	26.50	70.00	70.00
Manzoor Hussain Reti Dikka	6	2.73	2.63	1715.16	34.65	66.30	33.70	65.00	85.00
Pir Shafqat Reti Dikka	7	2.37	2.60	1622.80	37.46	38.90	61.10	90.00	75.00
Saeen Izzat Shah Reti Dikka	8	2.22	2.61	1640.80	37.10	36.60	63.40	85.00	60.00
Pak Army Operated Reti Dikka	9	2.25	2.46	1711.12	30.30	38.30	61.70	60.00	80.00
Mir Mushtaq Reti Dikka	10	2.34	2.47	1671.80	32.18	49.30	50.70	80.00	75.00
Matool Pathan Reti Dikka	11	3.17	2.60	1611.77	37.88	78.60	21.40	85.00	80.00
Min Value		2.20	2.46	1611.77	30.30	36.60	21.40	60.00	60.00
Max Value		3.17	2.66	1722.16	37.88	78.60	63.40	90.00	85.00
Mean Value		2.58	2.57	1659.90	35.12	57.59	42.41	77.27	74.55

3.1 Grain Size Distribution

Granulometric analysis results of sand samples (n=11) collected from Bholari River sand have been summarized in Table 2. Retained fractions of sand on various sieves varied in the order of mesh 16 (21.0%) > 50 (19.2%) > 30 (17.7%) > 100 (16.2%) > 8 (13%) > 200 (7.4%) > pan (5.1%). Coefficient of curvature (Cc) and uniformity curvature (Cu) were found to be 1 and 8 respectively.

Table 2. Grain Size Analysis result.

Reti Dikka	Sample #	Total Weight (g)	Mesh Number and Diameter in mm: 4	8	16	30	50	100	200	Pan	Total %	Coefficient of Curvature Cc	Uniformity Curvature Cu
			4.75	2.36	1.18	0.6	0.3	0.15	0.07				
			Weight Retained %										
Abandoned Reti Dikka (due to rain)	1	100	0.0	9.3	23.5	27.4	31.0	7.8	0.7	0.1	99.7		
River Channel	2	100	0.0	17.4	27.4	17.7	18.7	6.9	6.2	5.2	99.4		
Shah Jilani Reti Dikka	3	100	0.0	4.4	29.4	20.4	22.2	18.4	2.5	2.6	99.9		
Pir Shoukat Hussain Reti Dikka	4	100	0.0	8.7	19.8	6.2	23.0	33.5	6.0	2.5	99.6		
River Channel	5	100	0.0	14.8	21.6	16.0	16.1	14.3	12.2	4.2	99.1	1.08	8.14
Manzoor Hussain Reti Dikka	6	100	0.0	15.5	24.0	15.5	19.8	13.9	10.1	0.9	99.8		
Pir Shafqat Reti Dikka	7	100	0.0	17.9	10.3	18.7	14.8	21.0	7.4	9.2	99.3		
Saeen Izzat Shah Reti Dikka	8	100	0.0	4.7	19.1	17.4	21.6	20.4	10.2	6.4	99.6		
Pak Army Operated Reti Dikka	9	100	0.0	11.9	14.0	20.0	15.7	18.1	9.6	10.7	100.0		
Mir Mushtaq Reti Dikka	10	100	0.0	9.9	19.3	17.5	15.5	18.8	9.8	8.7	99.4		
Matool Pathan Reti Dikka	11	100	0.0	28.9	23.0	17.6	13.3	5.6	6.3	5.4	100.0		
Mean % Retained			0.0	13.0	21.0	17.7	19.2	16.2	7.4	5.1	99.6		
Mean % Passed			100.0	87.0	65.9	48.3	29.1	12.8	5.4	0.4			
Min Value			0.0	4.4	10.3	6.2	13.3	5.6	0.7	0.1			
Max Value			0.0	28.9	29.4	27.4	31.0	33.5	12.2	10.7			

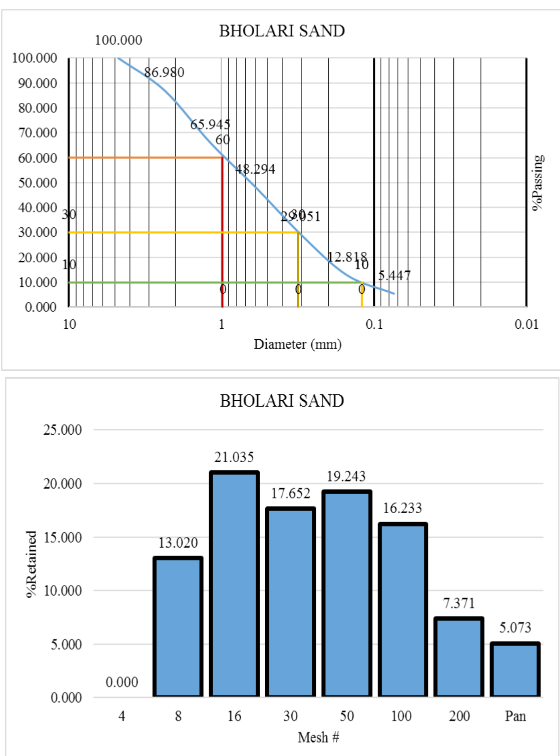

Figure 3. Graphical representation of cumulative frequency and grain size frequency histogram.

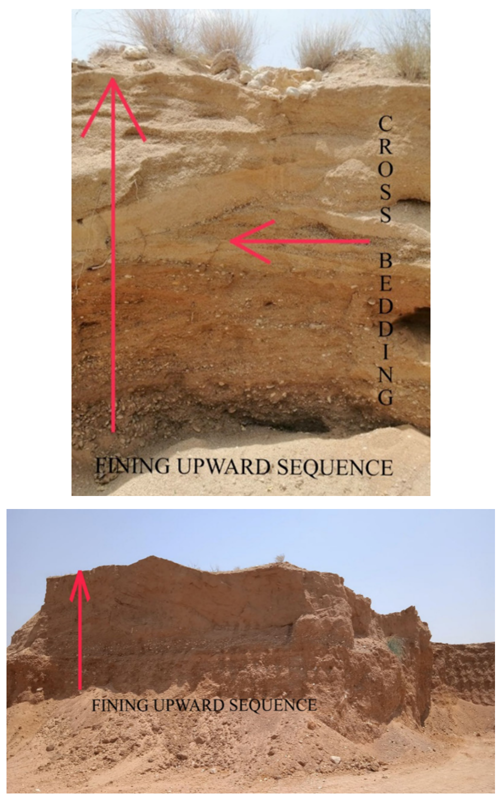

Figure 4. Show fining upward sequence and cross bedding.

3.2 Fineness Modulus

Fineness modulus (FM) is the most commonly computed factor for aggregates which is used to determine the degree of uniformity of aggregate gradation [13]. Data reveal that FM varies between 2.20-3.17 with a mean of 2.56 which is consistent with the ASTM C-33 range (2.3-3.1).

3.3 Specific Gravity

Specific gravity is an essential parameter for the design stage of structural elements to establish the concrete maximum and minimum weight. Moreover, it is a useful indicator of the suitability of an aggregate [13]. The specific gravity values of collected samples varied in the range of 2.47-2.64 with a mean of 2.56.

3.4 Bulk Density

Bulk density is also known as unit weight of aggregate. It is collectively used with specific gravity to calculate mixture proportion in concrete and also used to calculate voids between aggregates [20]. All samples are found to vary in the range of 1611.77 kg/m^3-1722.16 kg/m^3 with a mean of 1659.90 kg/m^3 for bulk density.

3.5 Carbonate Content

Carbonate content varied in the range of 38.60%-78.60% with a mean of 57.59% and Insoluble residue (IR) ranges between 21.40%-63.40% with a mean of 42.41%.

3.6 Petrographic Analysis

About all of the collected aggregate samples (n=11) of Bholari sand were subjected to petrographic examination. All the samples are earthy brown in color. A large number of bioclasts have been observed in the sand samples. The clast is made up of macro and micro fossils (mainly foraminifera). These fossil fragments are serving as carbonate sand fraction (Figure 6). Data revealed that the sediments varied in size from coarse to fine (0.2 mm-5 mm). Grain size analysis also revealed that examined sediments are well graded. On the other hand, grain shape of all the collected samples is found to be angular to sub-rounded. Morphological study of the sediments revealed that the percentage of angular, elongated, platy and rounded sediments varied as 77.27%, 12.27%, 4.27% and 6.18% respectively. Whereas, the surface texture roughness is found to be 74.55%. Microscopic examination also revealed the abundant occurrence of quartz and rock fragments (including bioclast) which is about 50% and 30% respectively. Besides, subordinate occurrence of feldspar (15%) followed by opaque minerals (<5%) is also observed. On the other hand, the occurrence of feldspar grains is confirmed by the presence of step like fractures and two cleavage sets that intersect at about 90^o [21]. Petrographic study revealed that Bholari River sand is devoid of clay, chert or any other deleterious material.

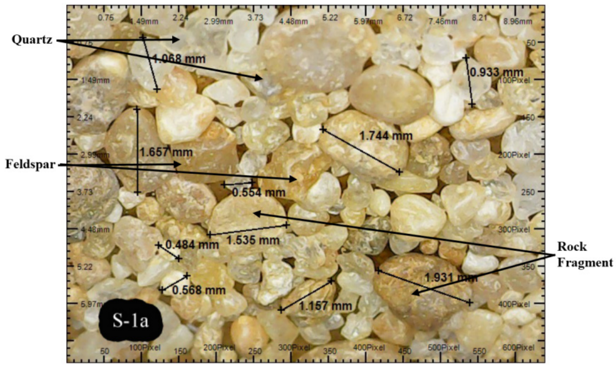

Figure 5. Mineral composition of Bholari river sand.

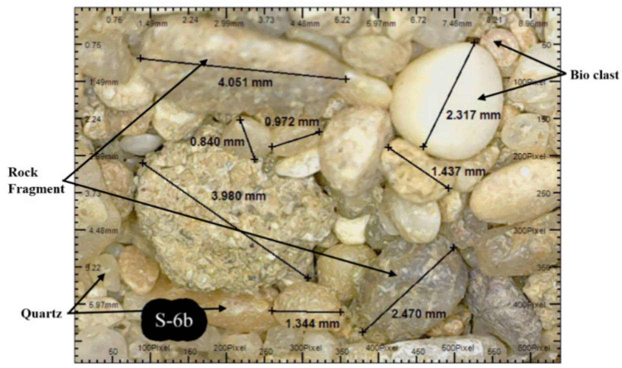

Figure 6. Microscopic view of Bholari sand showing foraminifera

4. Discussion

Bholari River flows from west to east direction against the strike direction of various rock formations. As a result, heterogeneous nature of the river influx occurs. Data reveal that Bholari sand mainly (70%) comprises of coarse to medium sand followed by about 30% fine to very fine sand. Grain size analysis indicates that Bholari River sand is well graded Bholari River flows along the transact of the various exposed lithologies that include Laki and Tiyon Formation, Nari Formation, Gaj Formation and Manchar Formation of Eocene, Oligocene, Miocene and Pliocene respectively. Well graded sediment influx in Bholari River is attributed to the heterogeneous rock source in the upstream area. The presence of FM in optimum range also justifies the sand to be well graded. Bholari river has been flowing with relatively high energy before the construction of Darawat dam and transported particles of all size including fine sand, coarse pebble, cobble and boulders.

However, the river flow decreased significantly after the construction of Darawat dam. Hence, the river is now capable only to transport sand size particles due to low energy. Moreover, cross bedding has been observed in Bholari River channel which shows the fluctuation in river flow pattern overtime due to the energy variations (Figure 4).

Relatively high density values (1611.77 kg/m^3-1722.16 kg/m^3) in collected samples show less clay content and large amount of sand particles. The occurrence of very fine particles (clay) in aggregate tends to interact with the bond between cement paste and aggregate, which is the cause of reduction in strength [22]. The occurrence of clay results in need of more water and more cement to hold. Thus increasing the cost whereas clay can weaken the bond in the concrete [23]. Bulk density measures the volume that the graded aggregate will occupy in concrete which also includes the solid aggregate particles and the voids between them. Void content of all samples varies between 30.30%-37.88% with a mean value of 35.12% which should vary between 40% to 50% for fine aggregate which is due to the dominance of angular grains.

Most of the particles in collected samples are angular (77.27%). Moreover, percentage of voids between aggregates also affects the aggregate grading which is important for concrete strength [24]. The strength of concrete depends upon the high bulk density coupled with less void content. The samples show high bulk density (1659.90 kg/m^3) and low void content (35.12%) as bulk density of aggregates has an inverse relationship with air voids which is in agreement with study carried by Alexander et al. [25]. Generally, high values of bulk density coupled with low percentage of void content will produce high strength concrete. High density is related to the roughness of the surface texture, which provides a greater bonding strength with asphalt cement and frictional resistance between particles because of better mechanical interlock [23,26].

Angularity of the aggregate also plays an important role in increasing or decreasing the bulk density of samples. Microscopic examination of the samples revealed that the average percentage of angular sediments in all collected samples is about 77.27%. Surface texture roughness is found to be 74.55% which indicates that the Bholari sand will give high strength to the concrete.

A sand is classified as carbonate sand when its carbonate content is in excess of 90%, a siliceous carbonate sand has a carbonate content of 50% to 90%, and the adjective calcareous is used for the deposits with a carbonate content of 10% to 50%. Hence, Bholari sand is siliceous carbonate in nature as the mean carbonate content is about 57% which is consistent with the fact that the river is passing along the transact of different lithologies comprising of sandstone, limestone, dolomite, shale etc. It is evident by the occurrence of nearly equal amount of all the lithologies. If calcium carbonate is used in the concrete as fine aggregate, it improves particle packing of the concrete and gives spacer effect, thus increasing the strength of concrete [27].

Petrographic analysis reveals a large number of bioclasts in the sand samples. The clast is made up of macro and micro fossils (mainly foraminifera). Data also revealed that the sediments varied in size from coarse to fine (0.2 mm-5 mm) which shows heterogeneity in the grain size of sand. Bholari River sand is angular to sub-rounded which reveals that the source is proximal and short distance transportation occurred.

Morphological study of the sediments revealed that the percentage of angular, elongated, platy and rounded sediments varied as 77.27%, 12.27%, 4.27% and 6.18% respectively. Whereas, the surface texture roughness is found to be 74.55%. A higher angularity and rough surface generates a stronger bond between paste and the aggregate creating a higher strength. Hence, Bholari sand qualifies to be used as fine aggregate. Mineralogically, Bholari sand is classified as lithic arenite in nature which contains 50% quartz, 30% rock fragments, 15% feldspar and <5% opaque minerals.

All parameters of aggregate suitability including specific gravity, bulk density, fineness modulus and carbonate content are also found within the specified range set by ASTM, AASHTO, BS and NHA. Therefore, Bholari River sand is suitable in terms of physico-mechanical properties.

5. Conclusions

It is concluded that Bholari sand is well graded comprising the siliciclastic minerals as main ingredient followed by limestone fragments. This sand is devoid of clay, chert or other deleterious material reactive to asphalt or cement. Hence Bholari sand can be used as fine aggregate for concrete work mixed with cement and asphalt.

Author Contributions

First author has executed the conceived idea of this project. Literature review, sampling, analysis and write up has been carried out by the first author. Study concept is created by co-author and supervised. Sample analysis and data interpretation has been cross checked by co-author. Review of paper, corrections and formatting in the template and submission to the journal as corresponding author has been carried out by co-author.

Conflict of Interest

It is declared that there is no conflict of interest.

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