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Assessment of Geotechnical Properties of Laki Limestone for Coarse Aggregate, Nooriabad, Jamshoro Sindh, Pakistan

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ABSTRACT

Present study is aimed at assessment of geotechnical properties of Laki limestone as coarse aggregate which is being quarried in Nooriabad area, Sindh, Pakistan. Coarse aggregate samples (n=20) of limestone were collected for the evaluation of physico-mechanical properties of the aggregate. Petrographic analysis revealed that the aggregate comprises of hard, compact, massive, crystalline and fossiliferous limestone. It is devoid of any reactive silica (chert, chalcedony) and other harmful constituents like clays or organic matter. Average values of specific gravity, absorption, bulk density, void content and combined index (EI + FI) of collected samples are 2.5, 2.1%, 1.54 g/cc, 38.55% and 13.04% respectively. The values of specific gravity (2.3-2.9), absorption (0-8%), bulk density (1.28 g/cc-1.92 g/cc) and void content (30%-45%) are varying within the range of normal weight aggregate as per American concrete institute (ACI) specifications. On the other hand, absorption values of aggregate samples are slightly higher (2.1%) than the reference range (2%) but meet other requirements. Mechanical properties including aggregate impact value (8.58%), aggregate crushing value (26.66%), Loss Angeles abrasion value (24.77%), sodium sulfate soundness (4.72%), water soluble sulfate (0.006%) and water soluble chloride (0.005%) are found to be within corresponding guidelines set by ASTM. On the other hand, average carbonate content is found to be 89.64% indicating that Laki limestone is of slightly low purity. Except absorption, all physical and mechanical properties lie within specified ranges. It is concluded that Laki limestone is suitable for use as road aggregate and concrete mix design.

1. Introduction

Coarse aggregate is the essential raw material for all types of construction i-e concrete and asphalt work ^[1].

It occupies major volume (up to 80%) of concrete ^[2]. Strength and durability of concrete is particularly a function of coarse aggregate ^[3]. Any geological material can be utilized as construction aggregate, if it meets end use

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specifications^[4]. Limestone is hard and durable rock to be used as an aggregate. The physico-chemical properties of aggregate material depend upon the geologic origin and mineral composition of the source including its subsequent weathering and alteration. Aggregate characterization can be divided into three categories including physical properties, mechanical properties and harmful contaminants. Limestone and dolomite are considered as hard and durable for use as an aggregate. Limestone quality for aggregate can be determined by several geological factors such as waste content, dolomitization level and degree of folding and faulting. There are many types of sandstone which are too porous and weak to be used other than construction filler material. However, relatively old and more indurated sandstone give higher strengths. Due to this reason, this type of sandstone may also be suitable as aggregate. On the other hand, igneous rocks usually produce strong aggregates with high skid resistance and hence are suitable for road surfacing, sub base material and aggregate base course in road construction. Igneous rocks are also good for railway ballast due to their high strength and attrition resistance^[5]. Igneous rocks are commonly used as construction aggregates in areas of igneous terrain and shield areas. Igneous rocks are hard and dense hence excellent source of aggregate. Some volcanic igneous rocks are too porous. Others containing volcanic glass and siliceous material are highly reactive to use as an aggregate. Pyroclastic material such as volcanic ash and volcanic tuff might be unfit as an aggregate directly but can be used after heating as they become compacted and cemented by this process. Metamorphic rocks can also be used as an aggregate material. The factor affecting their suitability for use as an aggregate is type of parent rock, degree and type of metamorphism and the subsequent alteration and weathering^[6,7].

Naturally occurring aggregate deposits (either sand and gravels or rock) all are formed by geological processes. The physical and chemical properties of aggregates result from the geologic origin and mineral composition of the potential source and its subsequent weathering and alteration. Most of the aggregate properties related to the grain size, texture, mineralogy, pore spaces and weathering products are observed and described by geological methods.

Pakistan is mainly a sedimentary terrain where limestone is the most common and widely exposed rock available throughout the country. Hence, it is the most common rock used in construction industry as construction aggregate. Aggregates are mainly produced by quarrying in Pakistan. After rock quarrying, crushing is performed for the classification of aggregate into various appropriate sizes for multiple uses.

In sedimentary rocks, limestone and dolomite are generally good source of crushed stone. However, some limestone and dolomite may be soft, friable and absorptive which may result in poor quality of aggregates. Chert, chalcedony, jasper, flint and all other cryptocrystalline silica as well as holohyaline material can cause adverse chemical reaction when used in cement concrete. Moreover, due to high surface energy and weak internal structure these are highly reactive. Hard and dense sandstone can also be used as aggregate material for use in construction.

Construction industry is the single largest user of aggregate in Pakistan. The specifications for aggregates to be used in concrete work are more precise than other uses. Aggregate quality has significant importance as it affects the performance, durability and mechanical properties of concrete^[8,9]. If aggregate satisfies these specifications than it almost meets all requirements for other uses. Aggregate characterization can be divided into three categories including physical properties, mechanical properties and other harmful contaminants.

Physical properties of aggregate include gradation, particle shape, surface texture, porosity, pore structure, specific gravity and change in volume which may affect the use of aggregate in concrete mix. Aggregates which are hard, durable and free from fractures are suitable for use in cement concrete and other constructions. On the other hand, particles that are friable, soft, highly fractured and having smooth surfaces are not suitable for used as construction aggregate. It is important to understand the geology of resource area, production process and reference methods for the evaluation of aggregates suitability to be used in construction. Mineralogical characters of coarse aggregate play fundamental role on making good quality aggregate^[10].

Chemical properties of aggregate affect the strength and durability of cement concrete as well as the bituminous work. The presence of certain contaminants can prevent the cement from hydrating or bitumen from adhering to the aggregate^[11]. Particles containing deleterious material, which may react with cement concrete, are harmful for use in concrete and other construction work.

Rapidly growing urbanization and ongoing CPEC (China Pakistan Economic Corridor) projects intend to increase the demand of construction raw material including aggregates in Pakistan. Characterization of aggregate is essential for selection of good quality and performance bound aggregate for construction purpose^[12]. Laki limestone (Eocene age) which is occurring in Nooriabad area is being quarried for used as construction aggregate in Karachi and adjoining areas. However, the suitability and in-service performance assessment of Laki limestone as

coarse aggregate has not been studied so far which may lead to huge economic loss and life threaten in the future. Therefore, this study is aimed at assessment of engineering properties of Laki limestone for its use in concrete mix design and asphalt work.

Study Area

Nooriabad is located in the vicinity of eastern part of Kirthar Basin where limestone of Laki Formation (Eocene age) is exposed as hills and ridges (Figures 1 & 2). Laki Formation is comprised of three members mainly Sohna, Laki and Tiyon. This Laki series was subdivided into basal Laki laterite (8 m), Meting limestone (45 m), Meting shale (30 m) and Laki Limestone (70 m-200 m) [13]. This formation contains micro fossils of foraminifera which suggest that the age of Laki Formation is early to middle Eocene. Structurally, Nooriabad is located in the synclinal valley formed by the erosion of limestone. Rocks in study area are highly deformed due to the occurrence of major folded structures. Study area is highly deformed by major anticlines and synclinal structures. Furthermore, Nooriabad is located in synclinal part of area. It is causing run off from adjacent hills towards the base area. Locally this area has two major faults i.e. Surjan and Jhimpir which occur around study area. According to Kazmi& Jan [14] further to the south and west of Lakhra, the north-south Surjan fault cuts across the Quaternary deposits. West of Jhimpir, the southern end of this fault is intersected by the north-west trading Jhimpir faults (Figure 1). The intersection of two faults is characterized by at least four teleseismic events of shallow focal depth and magnitude between 3-6 [14].

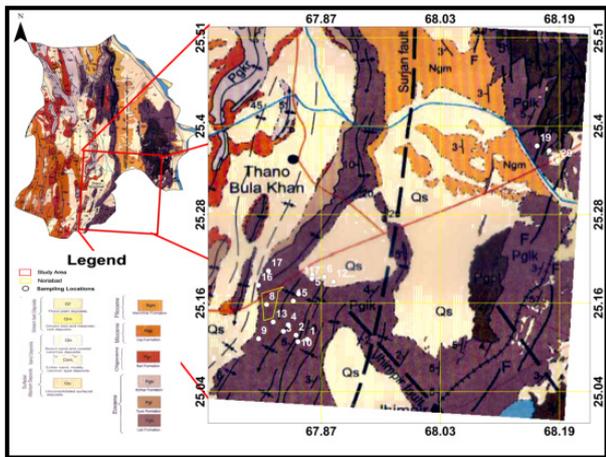


Figure 1. Geological map of study area.

2. Materials and Methods

Twenty coarse aggregate samples were collected from different crush plants operating in Nooriabad area (Figure 2). Samples were collected as per international reference

standard [15]. Aggregate samples were reduced to testing size according to ASTM C702 for performing different tests. The testing was divided into two parts (a) physical and (b) mechanical.

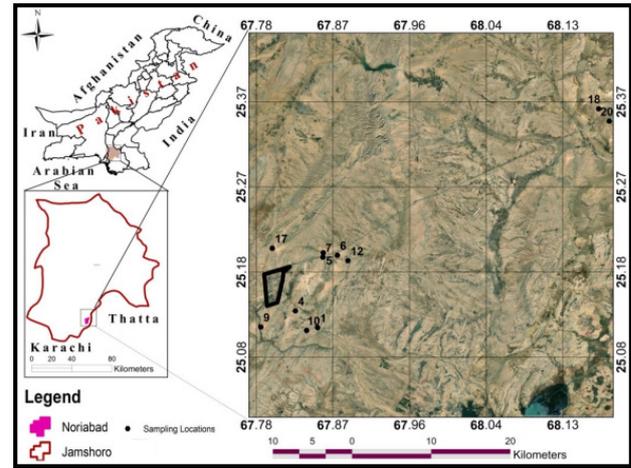


Figure 2. Samples location map.

2.1 Physical Properties of Aggregate

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

2.1.1 Particle Shape Analysis (ASTM D 4971)

Individual particles of coarse aggregate from specific sieves were measured to determine the width to thickness ratio by using Flakiness and Elongation gauge. Flakiness Index, Elongation Index and Combined Index (CI) were calculated on the basis of specific fractions.

2.1.2 Specific Gravity and Water Absorption (ASTM C127)

Specific gravity was determined in Oven dried (OD), Saturated Surface Dried (SSD) and Apparent conditions. The apparatus required for these tests are wire bucket of 3.35 mm, water tank and sieves of various mesh numbers (3/8, 1/2, 3/4, 1 and 1.1/2 inches). Following are the formulae of calculating different specific gravity values:

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

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

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

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

2.1.3 Bulk Density (ASTM C 29)

Bulk density and void content were determined by us-

ing 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 the following formula:

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

where,

M= Aggregate bulk density (kg/m³)

G = Mass of the aggregate including measure (kg)

T = Mass of measure (kg)

V = Volume of measure (m³)

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/m³)

S = Bulk specific gravity (dry basis)

W = Density of water (998 kg/m³)

Volume of measure was calculated by using following formula:

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

where,

V = Volume of measure (m³)

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/m³)

2.2 Mechanical Properties

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

2.2.1 Aggregate Strength Test

Aggregate strength was determined by conducting Aggregate Impact Value (BS-812), Aggregate crushing value ^[15] and Loss Angeles Abrasion Value ^[16]. These tests were used to determine the strength, toughness and abrasion resistance of aggregate against sudden and repetitive forces.

2.2.2 Aggregate Durability Test

Soundness of aggregate was determined for the durability evaluation of aggregate. ASTM C 88 ^[17] standard was followed to assess the chemical soundness of aggregate.

2.3 Carbonate Content of Aggregate

Carbonate content of aggregate was determined to assess the chemical grade and purity of limestone aggregate using ASTM D4373 ^[18].

2.4 Petrographic Examination (ASTM C 295)

Petrographic examination of limestone aggregate was car-

ried out for the determination of mineral composition and the presence of alkali silica reactive material in aggregate.

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.

3.1 Particle Shape Analysis

Shape and orientation of aggregate particle is necessary for the production of workable concrete. Flakiness and elongation of individual particles were measured for particle shape analysis. FI and EI varied between 2.0-8.1 and 3.2-18.5 with a mean of 5.65±1.68 and 7.38±3.26 respectively. FI and EI of all the samples are within the specified range set by ASTM and NHA as well.

3.2 Specific Gravity and Water Absorption

Specific gravity is used in aggregate strength assessment. It is mainly used in the weight volume calculation of mix design. Bulk SG values of all samples vary within the range of 2.46 to 2.57 with a mean of 2.51±0.02. While, SSD specific gravity values ranges between of 2.51 to 2.64 with average of 2.60±0.03. On the other hand, apparent SG varies between 2.57-2.69 with a mean of 2.64±0.02. Specific gravity is the inherent property of material and function of parent rock composition which varies place to place and due to this, limits for specific gravity have not been set in the standards ^[19].

Absorption values of all the samples vary between 0.56 to 3.09 with a mean value of 2.10±0.5. As per ASTM, AASHTO, BS and NHA standards, absorption values should be less than 2% for concrete mixes and asphalt work. Samples have shown absorption values slightly higher than the standard range where only sample 10 shows highest absorption value (3.09%). Absorption is the indirect measurement of aggregate porosity ^[20]. High values of porosity lead to the serious durability concerns. It is used in the calculation of mixing water quantity in concrete and if it is not absorbed by the aggregates, it can cause the decrease in compressive strength of concrete ^[21].

3.3 Bulk Density

All the samples lie in the range of normal weight aggregate where bulk density values ranges between 1.45 g/cc-1.61 g/cc with an average of 1.54±0.04 g/cc. Void contents lie between 34.68%-41.94% with a mean of 38.55±1.97%. Results of bulk density are also used in the calculation of mix design.

Table 1. Aggregate samples testing results.

S.No	Specific Gravity (Apparent)	Specific Gravity (SSD)	Specific Gravity (OD)	Water Absorption (%)	Bulk Density (g/cc)	Void Content (%)	Flakiness Index %	Elongation Index %	Combined Index %	Loss Angeles Abrasion Value (%)	Sodium Sulphate Soundness Test (%)	Aggregate Crushing Value (ACV) %	Aggregate Impact Value(AIV) %	Carbonate Content (CaCO3 %)	Insoluble Residue (IR) %	Sulfate (%)	Chloride (%)
1	2.63	2.61	2.52	1.91	1.46	41.947387	6	7	13	21	5.1	22	6.47	88.86	11.14	0.002	0.002
2	2.65	2.6	2.5	1.92	1.45	41.883768	5	4	9	20	5.3	24	6.68	88.98	11.02	0.007	0.002
3	2.62	2.59	2.49	2.03	1.55	37.626257	8	5	13	18	4.9	26	9.96	89.24	10.76	0.005	0.004
4	2.62	2.6	2.51	2.1	1.48	40.917692	4.5	6	10.5	20	5.6	23	6.89	87.88	12.12	0.013	0.002
5	2.66	2.62	2.5	2.04	1.45	41.883768	7	6.7	13.7	18	5.21	21.78	4.74	91	9	0.005	0.002
6	2.68	2.63	2.56	2.15	1.56	38.940381	4	8	12	23	5.9	21.80	11.13	87.8	12.2	0.001	0.002
7	2.63	2.64	2.53	1.54	1.56	38.216354	4.5	9.3	13.8	27	4.26	24.88	8.45	92.1	7.9	0.003	0.004
8	2.691	2.58	2.57	0.56	1.57	38.788082	6	6	12	20	5.42	22.22	8.68	90.2	9.8	0.014	0.001
9	2.67	2.61	2.53	1.85	1.58	37.424256	5.5	12.03	17.53	23	3.7	19.70	4.25	87.86	12.14	0.002	0.001
10	2.57	2.511	2.47	3.09	1.61	34.687188	2	3.2	5.2	30	3.33	28.15	8.00	89.5	10.5	0.001	0.006
11	2.67	2.63	2.51	2.4	1.51	39.720078	5.8	6.5	12.3	25	4.25	26.2	9.70	87.9	12.1	0.007	0.006
12	2.66	2.6	2.539	2.03	1.57	38.040713	7.6	7.2	14.8	26	4.53	27.85	9.14	89	11	0.008	0.008
13	2.66	2.61	2.51	2.12	1.53	38.921668	6	7	13	26.7	4.56	24.5	8.20	88	12	0.008	0.007
14	2.67	2.6	2.5	2.1	1.56	37.47495	5	8	13	28	4.52	25.3	10.20	88	12	0.006	0.006
15	2.67	2.62	2.53	2.09	1.54	39.008452	8.1	6.2	14.3	27	4.59	28.1	8.20	88.5	11.5	0.007	0.006
16	2.63	2.61	2.51	2.2	1.55	38.123258	7.7	5	12.7	25	5.1	22.68	7.81	89	11	0.007	0.007
17	2.6	2.54	2.461	2.9	1.56	36.484102	3.1	5.9	9	24	5.45	31.65	15.24	89.7	10.3	0.008	0.012
18	2.64	2.58	2.462	2.91	1.58	35.695925	4.1	9.2	13.3	29.84	4.11	23.99	9.77	92.44	7.56	0.015	0.007
19	2.67	2.62	2.535	2.03	1.58	37.547679	5.6	18.5	24.1	30	3.94	24.12	8.01	93.86	6.14	0.005	0.004
20	2.66	2.6	2.51	2.1	1.56	37.724054	7.59	7	14.59	34	4.81	25.40	10.15	93.06	6.94	0.004	0.003
Min	2.57	2.511	2.461	0.56	1.45	34.687188	2	3.2	5.2	18	3.33	19.7016781	4.25	87.8	6.14	0.001	0.001
Max	2.691	2.64	2.57	3.09	1.61	41.947387	8.1	18.5	24.1	34	5.9	31.65	15.24	93.86	12.2	0.015	0.012
Mean	2.64755	2.60005	2.51235	2.1035	1.5405	38.5528	5.6545	7.3865	13.041	24.777	4.729	24.6664453	8.58	89.644	7.735	0.006	0.005
SD	0.02978957	0.0302802	0.0288011	0.52382475	0.0463936	1.9755546	1.68539695	3.26354066	3.65661175	4.4267192	0.67269998	2.81110353	2.37157543	1.87733966	1.8773397	0.0041	0.00283

3.4 Aggregate Strength Tests (ACV and AIV)

Aggregate strength is one of the index parameters to be used in concrete and road aggregate. Aggregate Impact Value (AIV) and Aggregate Crushing Value (ACV) are used to determine the aggregate strength and toughness. AIV of all the samples varies between 4.25%-15.24% with a mean of 8.58±2.37% which is within the standard range of 4% to 11% except sample 17 (15.24%). Similarly, ACV of all samples lies between 19.7%-31.65% with a mean of 24.66±2.81%. Generally, crushing values of aggregates less than 30% are acceptable. However, the lower the crushing value, stronger will be the aggregates [22]. Maximum permissible limit for crushing value is 30% and 15% for base and wearing course respectively (Arshad & Qui, 2012). ACV values vary within the range of 19 to 28 except sample 17 (31.65%). Sample 17 shows the highest AIV and ACV values which are 15.24% and 31.65% respectively. AIV of aggregate between 10%-20% are classified as strong aggregate. Hence, Laki limestone falls in strong aggregate class.

3.5 Loss Angeles Abrasion Value (LAAV)

Loss Angeles Abrasion Value (LAAV) of Laki limestone was determined for assessment of aggregate toughness [23]. Toughness is the ability of material to show resistance against impact and abrasion due to traffic load. Interestingly, all the samples fall within the range of 18%-34% with a mean of 24.77±4.42%. Except S-20 (LAAV = 34%) all the samples lie in the range of 18%-30% for LAAV. Recommended value of LAAV for aggregate sub

base is 50%, base course 40%, asphalt & cement concrete 30% [15]. Hence, all the samples of Laki limestone aggregate lie within the specifications set by ASTM and NHA. Evaluation of aggregate durability is essential for determination of its resistant to abrasion and polishing [24,25]. AIV and LAAV are collectively used to assess aggregate performance and durability [26]. Hence a common pattern of data tends toward the low value of LAAV which indicates harder aggregate [27].

3.6 Soundness

Aggregate Soundness value is used to identify either aggregate is prone to degradation in saturated moisture condition, elevated temperature and freezing condition [18]. All collected samples of Laki limestone aggregate show soundness values lies between 3.3% to 5.9% with a mean value of 4.7±0.67 % (Table 1). Sample 10 shows lowest (3.3%) while 6 shows the highest (5.9%) soundness values. 12% soundness value is acceptable (with sodium sulphate) for used as aggregate base course material while 10% for use in Portland cement concrete [28]. On the other hand ASTM allows maximum limit of 18% loss after 5 cycles (ASTM C88). Soundness is the physico-chemical disintegration of aggregate which is also used to assess its durability and aggregate should be sound for resistance to intense weathering condition [29,19,30]. All the samples vary within specified limits set by ASTM and AASHTO and can be considered as sound.

3.7 Petrographic Examination

About half of the collected aggregate samples (n=11)

of Laki limestone were subjected to petrographic examination. Aggregate is found to be calcitic in composition and chemically it is calcium carbonate (Figures 3-6). Microfossils (Foraminifera) are reported to occur in all samples which are clearly visible in microscopic study. Since, fossils are biochemically precipitated, calcite is more pure as compared to chemically precipitated and contains homogeneous structures. Hence, it is more stable and relatively less reactive material toward cement or asphalt. Based on grain to matrix ratio, most of the samples are classified as micrite (Mudstone, less than 10% grain) while two are termed as Packstone (grain supported) and one sample (S-9) is Wackstone^[30]. It is obvious from the study that micro fractures also occur in about half of the samples which is indicator of compressional forces. In sample 5, microfractures are filled with recrystallized lime mud known as sparite (Figure 5). Micrite is amorphous material while sparite is crystalline which is relatively more stable and non-reactive as compared to micrite. Presence of stylolitic suture also confirms the response of compressional tectonic forces which has improved the mechanical and chemical quality of Laki limestone. Organic matter is also reported in some of the samples which is shown in thin section as dark brown or black streaks visible both in plane polarized light and cross nicol mode. Samples manifested the occurrence of fractured, non-fractured, micritic, sparitic and stylolite features. All samples have angular to sub angular grains with fractured surfaces and less than 10% flat and elongated particles. These are free from clay, chert and any other reactive siliceous material harmful for concrete.

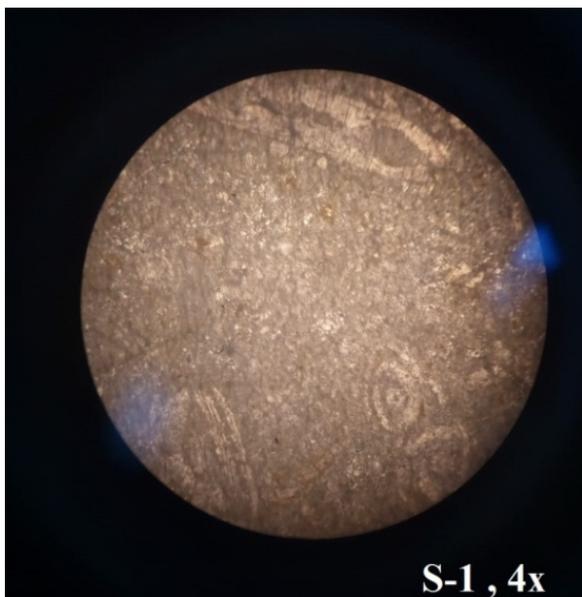


Figure 3. Microfossils in sample 1

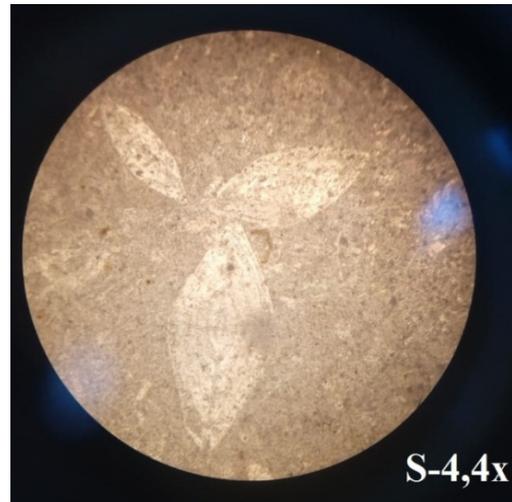


Figure 4. Microfossils and organic matter visible in sample 2

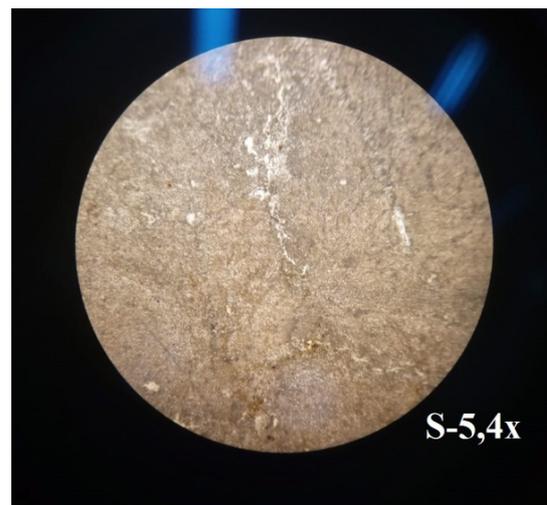


Figure 5. Stylolitic sutures and microfractures Filled with sparite

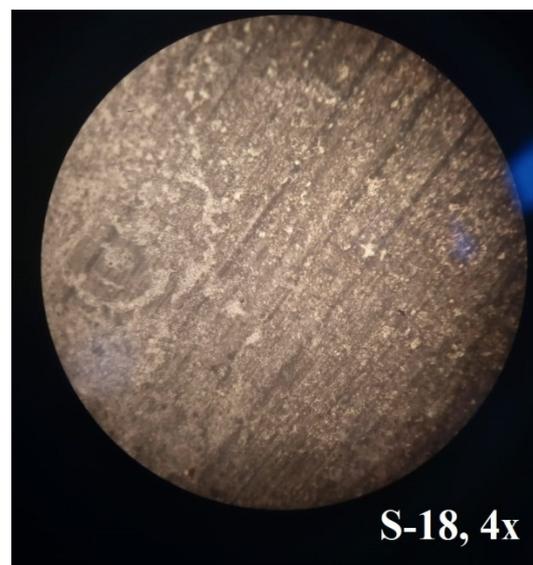


Figure 6. Microfossils and 1 set calcitic cleavage

All samples (n=20) of Laki limestone aggregate have chloride content ranging between 0.001%-0.012% with an average of 0.005%. These values are within the specified range given by American Concrete Institute (Table 2).

Table 2. Chloride ion (%) limit in concrete.

Chloride limit in Concrete.			
Category of reinforce concrete	Maximum chloride ion content in concrete (percent by weight of cement)		
	Acid-soluble (ASTM C-1152)	Water soluble (ASTM C-1218)	Water soluble (ACI 222.1)
Pre-stressed (or Post-tensioned)	0.08 (40%)	0.06 (40%)	0.06 (40%)
Non-prestressed (Wet condition)	0.1 (50%)	0.08 (53%)	0.08 (53%)
Non-prestressed (Dry condition)	0.20 (100%)	0.15 (100%)	0.15 (100%)

Sulfate content in all collected samples are ranging from 0.001%-0.015% with an average of 0.006%. These values are below the permissible limit given by ACI (Table 3).

Table 3. Recommendation for normal weight concrete subject to sulfate attack (ACI 201).

Sulphate exposure	Water soluble sulfate in soil/rock (%)	Water soluble sulfate in water (ppm)	Cement type	Water cement ratio
Mild	0.10	150	-	-
Moderate	0.10-0.20	150-1500	Type II IP(MS) IS(MS) Type II + Pozzoloan	0.5
Severe	0.20	1500	Type V Type II + Pozzoloan	0.45

3.8 Statistical Analysis

Aggregate testing data were also analyzed statistically by using SPSS software. SPSS is a software which is used for data management and to represent the data statistically. Pearson correlation, cluster analysis and test of normality were run on the results of collected samples.

3.8.1 Pearson Correlation

Pearson correlation is run on results data to determine the significant correlation among all parameters (Table

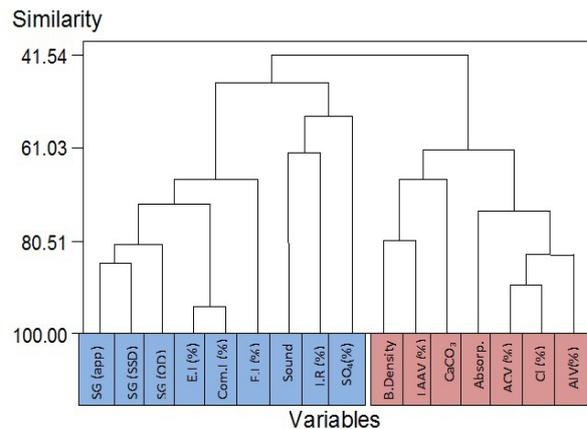
4). This significant correlation is either positive or negative. Pearson correlation with 2 tail level of significance (0.01 and 0.05) is used. Combined Index shows positive correlation while absorption shows a negative correlation with SG. Bulk density shows an inverse relation with void content. On the other hand ACV and AIV shows a positive correlation with each other and also with combined index.

3.8.2 Test of Normality

Two tests of normality (Kolmogorov-Smirnov and Shapiro-Wilk) were run on data by using SPSS software with 5% level of significance (Table 5). The outcome of these tests revealed that about half of the samples are normally distributed.

3.9.3 Cluster Analysis

Data are classified into two groups with the help of cluster analysis (Figure 7). Parameters including specific gravity (OD, SSD, and AP), combined index (FI and EI), soundness, IR and sulfate are gathered in one group. On the other hand, absorption, bulk density, LAAV, AIV, ACV, carbonate and chloride content are combined in other group. As discussed above the correlation between CI and SG is linear and relationship between soundness and bulk density is inverse. Hence, it can be concluded that in cluster I, all the parameters have a direct relationship with each other while, in cluster II, parameters are inversely proportional to each other.



Cluster 1: SG(app), SG(SSD), SG(OD), F.I, E.I, Com.I, Soundness, I.R, Sulfate

Cluster 2: Absorption, Bulk Density, LAAV, ACV, AIV, Carbonate content, Cl

Figure 7. Cluster analysis of the data.

4. Discussion

Aggregate of Laki limestone is suitable in terms of phys-

Table 4. Pearson correlation at level of significance 0.01 and 0.05.

Correlations																
	SG (App)	SG (SSD)	SG (OD)	W. Abs (%)	Bulk D (g/cc)	FI (%)	EI (%)	C. Index (%)	L.AAV (%)	Soundness (%)	ACV (%)	AIV (%)	CaCO ₃ (%)	IR (%)	SO ₄ (%)	Cl (%)
	P.Corre	1	.665**	.705**	-.591**	-.066	.451*	.407	.571**	.152	-.439	-.164	-.023	.023	.131	-.374
	Sig. (2-tailed)		.001	.001	.006	.781	.046	.075	.008	.910	.523	.490	.923	.923	.581	.105
	P.Corre	.665**	1	.589**	-.460*	-.368	.504*	.397	.586*	.172	-.500*	-.333	-.021	.021	-.137	-.395
	Sig. (2-tailed)			.006	.041	.110	.024	.083	.007	.581	.468	.151	.929	.929	.565	.085
	P.Corre	.705**	.589**	1	-.789**	.029	.345	.313	.438	-.161	.228	-.462*	-.100	.100	-.103	-.530*
	Sig. (2-tailed)				.000	.902	.137	.179	.053	.499	.333	.040	.674	.674	.666	.016
	P.Corre	-.591**	-.460*	-.789**	1	.161	-.414	-.133	-.309	.391	-.306	.500*	-.019	.019	-.123	.618**
	Sig. (2-tailed)					.498	.070	.577	.185	.088	.189	.025	.145	.937	.605	.004
	P.Corr	-.066	-.368	.029	.161	1	-.218	.296	.164	.610**	-.523*	.288	.402	.248	-.058	.351
	Sig. (2-tailed)						.356	.205	.490	.004	.018	.218	.079	.293	.809	.129
	P.Corr	.451*	.504*	.345	-.414	-.218	1	-.011	.451*	-.136	.152	-.141	-.250	.018	.046	-.137
	Sig. (2-tailed)							.963	.046	.569	.523	.553	.289	.941	.848	.564
	P.Corr	.407	.397	.313	-.133	.296	-.011	1	.887**	.318	-.369	-.287	-.135	.471*	-.115	-.145
	Sig. (2-tailed)								.000	.172	.109	.220	.569	.036	.629	.541
	P.Corr	.571**	.586**	.438	-.309	.164	.451*	.887**	1	.221	-.259	-.321	-.236	.429	-.082	-.193
	Sig. (2-tailed)									.349	.269	.168	.317	.059	.732	.415
	P.Corr	-.027	-.131	-.161	.391	.610**	-.136	.318	.221	1	-.588**	.356	.290	.455*	-.455*	.401
	Sig. (2-tailed)										.006	.123	.214	.044	.661	.080
	P.Corr	.152	.172	.228	-.306	-.523*	.152	-.369	-.259	-.588**	1	-.157	.228	-.240	.239	-.184
	Sig. (2-tailed)										.006	.509	.333	.309	.310	.436
	P.Corr	-.439	-.500*	-.462*	.500*	.288	-.141	-.287	-.321	.356	-.157	1	.683**	.044	-.044	.058
	Sig. (2-tailed)										.509	.001	.855	.855	.808	.000
	P.Corr	-.164	-.333	-.254	.338	.402	-.250	-.135	-.236	.290	.228	.683**	1	.073	-.073	.153
	Sig. (2-tailed)										.333	.001	.758	.758	.520	.002
	P.Corr	-.023	-.021	-.100	-.019	.248	.018	.471*	.429	.455*	-.240	.044	.073	1	-.1000**	.066
	Sig. (2-tailed)										.309	.855	.758	.000	.782	.925
	P.Corr	.023	.021	.100	.019	-.248	-.018	-.471*	-.429	-.455*	.240	-.044	-.073	-.1000**	1	-.066
	Sig. (2-tailed)										.309	.855	.758	.000	.782	.925
	P.Corr	.131	-.137	-.103	-.123	-.058	.046	-.115	-.082	-.105	.239	.058	.153	.066	-.066	1
	Sig. (2-tailed)										.310	.808	.520	.782	.782	.401
	P.Corr	-.374	-.395	-.530*	.618**	.351	-.137	-.145	-.193	.401	-.184	.795**	.655**	-.022	.022	.199
	Sig. (2-tailed)										.436	.000	.002	.925	.925	.401

** . Correlation is significant at the 0.01 level (2-tailed).

* . Correlation is significant at the 0.05 level (2-tailed).

Table 5. Statistical variables showing Normal Distribution of data at Level of Significance (LOS) 5%.

	Tests of Normality					
	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
	Statistic	Df	Sig.	Statistic	Df	Sig.
Specific Gravity (Apparent)	.212	20	.019	.915	20	.080
Specific Gravity (SSD)	.249	20	.002	.843	20	.004
Specific Gravity (OD)	.134	20	.200*	.959	20	.532
Water Absorption (%)	.227	20	.008	.837	20	.003
Bulk Density (g/cc)	.231	20	.006	.862	20	.008
Flakiness Index %	.125	20	.200*	.958	20	.506
Elongation Index %	.225	20	.009	.788	20	.001
Combined Index %	.215	20	.016	.867	20	.010
Loss Angeles Abrasion Value (%)	.110	20	.200*	.964	20	.628
Sodium Sulfate Soundness (%)	.109	20	.200*	.983	20	.970
Aggregate Crushing Value (ACV) %	.102	20	.200*	.963	20	.615
Aggregate Impact Value (AIV) %	.148	20	.200*	.935	20	.188
Carbonate Content (CaCO ₃ %)	.188	20	.062	.854	20	.006
Insoluble Residue (IR) %	.188	20	.062	.854	20	.006
Sulfate (%)	.195	20	.045	.914	20	.077
Chloride (%)	.169	20	.137	.909	20	.060

ical and mechanical properties. Flakiness and elongation indices values are less than 15%. Other parameters of aggregate suitability including LAAV, AIV, ACV and soundness are also found within the specified range set by ASTM, AASHTO, BS and NHA. Specific gravity of all the samples lies within the range of limestone. On the other hand, only results of water absorption are slightly higher values than the reference range but samples meet other requirements as other physical and mechanical properties lie within the specific ranges. Laki limestone has also been tested for chemical properties and mineral composition. Data revealed that Laki limestone is of relatively low chemical purity and mainly micritic in nature which contains lime-mud associated with organic matter. Micro fractures are also obvious in response to compressional tectonics in study area. Bulk density of all the collected aggregates also lies within the range of normal weight aggregate.

5. Conclusions

All the collected samples (n=20) of Laki limestone were tested for the evaluation of Physico-chemical and mechanical properties, mineral composition and chemical purity. All the strength parameters of aggregate including

LAAV, AIV and ACV are found within the reference range set by ASTM, AASHTO, BS and NHA. Mineralogically, Laki is micritic limestone and chemically it is low purity grade. Aggregate of Laki limestone is lies in the category of normal weight aggregate. Hence, it is concluded that Laki limestone aggregate is suitable to be used as coarse aggregate material in cement concrete. It is also suitable for used in road construction for aggregate sub base, aggregate base course and asphaltic base course material.

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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