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AGGREGATE POTENTIAL OF KHAIRABAD LIMESTONE, KALABAGH-MIANWALI, PAKISTAN

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ABSTRACT: Quality of aggregate material reflects the physical, chemical and mineralogical properties of source rock. Limestone is main source of crushed rock aggregate, which is largely used by construction industry. There are few geological formations in Kohat-Potwar province which qualify the specific criteria for utilization as aggregate in building material. Khairabad Limestone exposed in Kalabagh area in Western Salt Range contains colossal quantity of minable aggregates. That's why, we quantitatively examined this limestone of Paleocene age through several physical, chemical, mineralogical, engineering and mechanical tests to evaluate its aptness as aggregate material. AASHTO, ASTM, BS and NHA designated engineering tests including Los Angles Value (26.59%), Aggregate Impact Value (13.91%), Aggregate Crushing Value (12.84), soundness value (1.84%), coating and stripping of bitumen (96.4%), specific gravity (2.7), water absorption (0.83%), unit weight (1.65 g/cm3), total (elongation + flakiness) index (22.78%), and petrographic analysis (ASR & ACR) revealed that it is highly feasible aggregate resource with suitable properties. Investigated reserve is vast and thick enough to provide aggregate material to nearby local construction as well as national megaprojects. It would be a good contribution to the rising demand of construction materials in the country.

Key words: Khairabad Limestone; aggregate; engineering properties; Western Salt Range.

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INTRODUCTION

Aggregate is a broad category of coarse crushed rock material used in various construction purposes. The aggregate serves as reinforcement to add strength to the overall composite material. Variety of rocks including granite, gabbro, dunite, marble, sandstone and limestone are generally mined and crushed as natural aggregate sources. High performance and fine quality aggregates which meet the international standards are preferred for utilization in construction purposes (Kandhal & Parker, 1998; Fookes et. al., 1988; Ahsan et. al., 2000). For this purpose, aggregate must qualify certain chemical and physical parameters. Quality of aggregate material directly depend upon properties of source rock (Naeem M. et al., 2014). The advent of modern blasting methods and crushing plants have enabled development of quarries anywhere in the world to excavate competent rock formations for quality crushed rock aggregates (Khan and Chaudhry, 1991). Construction industry is the second largest sector of Pakistan's economy after agriculture. Several megaprojects are afoot to upgrade and expand widespread intercity network of roads and highways. Government has decided to build already planned as well as new dams to boost the clean and renewable power production for next decade. Furthermore, China-Pakistan Economic Corridor (CPEC) is a socio-economic development program that stretches throughout Pakistan. Although it is primarily associated with infrastructure, it has multiple backward and forward linkages with other sectors. CPEC includes major projects of expressways, railway, energy sector, Gawadar port and city, science and technology, agriculture and power generation. Limestone aggregate will be extensively utilized in their construction. The road network of CPEC runs throughout from northern Pakistan through Karakoram and Himalayas to Gawader in the southern Pakistan.

Salt Range is located at the peripheral part of the Himalayan Orogenic Belt and western route of CPEC runs in the proximity of western Salt Range across the Indus River (Chaudhry and Ghazanfar, 1993). The Salt Range of northern Pakistan crops out a thick Neoproterozoic-recent sedimentary package just north of Punjab Plains (Gee, 1945). The sedimentary sequence of Salt Range exposed various limestone units including Wargal limestone, Lockhart limestone, Sakesar limestone and Chorgali Formation etc. (Gee, 1945; Shah, 2009; Yasin et al., 2015; Munawar et al., 2022). Many investigators worked on limestone units of Salt Range and Trans Indus ranges to evaluate the aggregate potential of these rock units in order to combat the aggregate need of the country (Gondal et al., 2009; Ahsan et al., 2012; Rehman et al., 2018). Gondal et al., (2009) investigated Jutana Dolomite, Sakesar limestone and Lockhart limestone reserves in Eastern and Central Salt Range. Ahsan et al., (2012) studied the aggregate suitability of Wargal limestone, Lockhart limestone and Sakesar Limestone exposed at Dhak Pass in Western Salt Range.

In this study, Paleocene Khairabad Limestone of Kalabagh area (Fig. 1) has been analyzed physically, chemically as well as mineralogically for its suitability as aggregate in concrete work. Alkali silica reaction (ASR), alkali carbonate reaction (ACR) and petrographic analysis of Khairabad Limestone was executed in Institute of Geology, University of the Punjab, Lahore. Engineering properties of aggregate material are determined by ASTM, AASHTO, British Standard (BS) and National Highway Authority (NHA) recommended aggregate tests.

Regional Geology: Salt Range is located at the southern margin of the Himalayan Orogenic Belt as frontal mountain range and it lies in the geological domain Sub Himalayas (Fig. 1). It is considered as surface expression of a decollement which lies within evaporites of Precambrian to infra–Cambrian Salt Range Formation and it emplaced the older strata over the Punjab Plain (Crawford, 1974). Salt Range is delimited by Salt Range Thrust and Potwar Plateau in the south and north, respectively and truncated by Jhelum Fault and Kalabagh Fault in the east and west, respectively (Gee, 1989). The presence of evaporitic facies at base of Salt Range significantly caused salt diaprism which developed the numerous normal faults within compressional regime (Yeats and Lawrence, 1984). Stratigraphically, it is comprised thick sedimentary sequence (Fig. 2) ranging in age from Precambrian to recent (Gee, 1989). Base of the Salt Range is represented by evaporites of Precambrian-Early Cambrian Salt Range Formation which is followed by thick Palaeozoic strata with a major unconformity between Cambrian and Permian (Gee, 1980; Shah, 2009; Rehman et al., 2015; Meng et al., 2021; Rahman et al., 2022). Palaeozoic of is overlain by clastic-carbonate package of Mesozoic in Salt Range and Trans Indus ranges which further followed by Paleogene carbonate with siliciclastic rocks (Shah, 2009; Munawar et al., 2022; Khan et al., 2023). Paleogene strata is capped by Neogene molasse sediments with an unconformable contact (Gee, 1980; Shah, 1977, 2009).

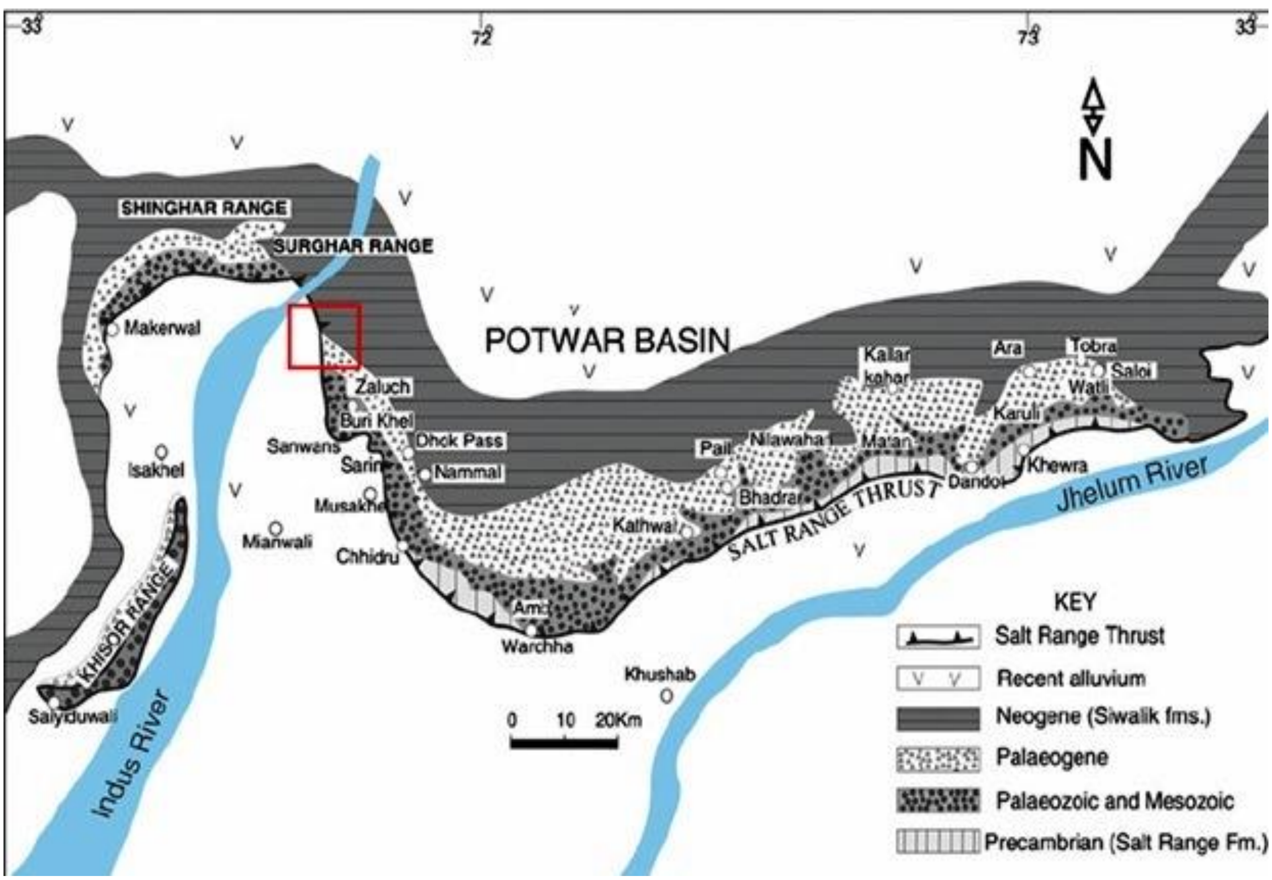

Figure 1: Location and simplified geologic map of Salt range (modified after Gee 1989 and Ghazi and Mountney 2009). Squared area refers to the area of study.

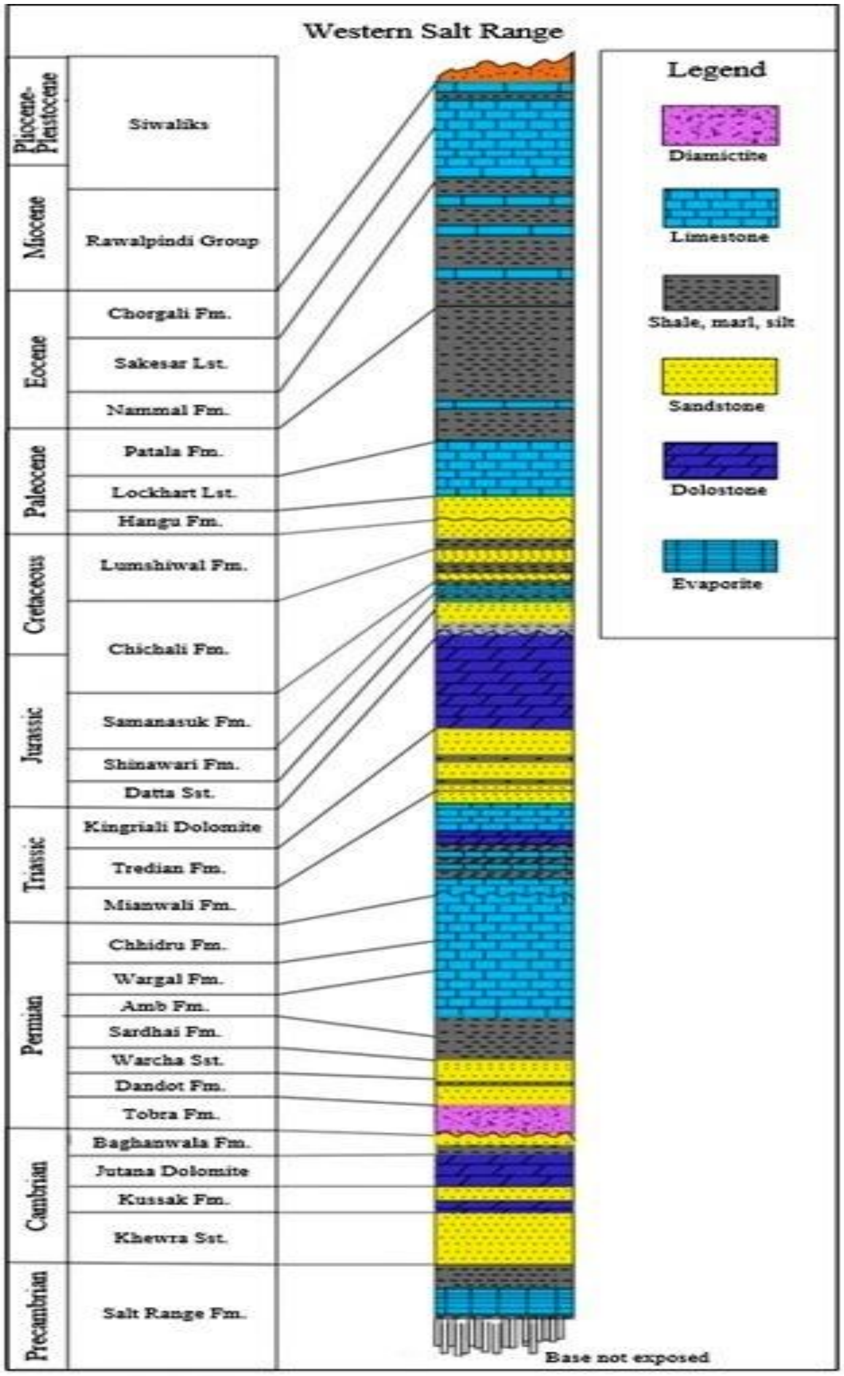

Figure 2: Generalized stratigraphic sequence of Western Salt Range (after Gee, 1980)

MATERIALS AND METHODS

Sufficient quantity of fresh rock samples from Khairabad Limestone were collected during fieldwork, with characterization of megascopic properties and outcrop zoning. Samples were prepared in obedience to standard method of aggregate sampling (ASTM D75). Then samples were crushed into various crush sizes and conserved in bags, and transported to laboratory.

Lab-work comprised of mineralogical and engineering geological investigation of limestone samples. Petrographic thin sections were prepared and analysed using Nikon Polarizing Microscope in mineralogy lab of Institute of Geology, University of the Punjab, Lahore. Petrographic analysis helped in categorization of limestone according to the Dunham (1962) and Flügel (2004) classification. ASTM, AASHTO, British Standard (BS) and National Highway

Authority (NHA) recommended aggregate tests were conducted at engineering geology laboratory of Institute of Geology, PU Lahore, to investigate physical and material engineering parameters of aggregate samples. These tests include Los Angeles Abrasion (AASHTO T-96 / ASTM C-131), Aggregate Impact Test, Aggregate Crushing Test, Soundness Test (AASHTO T-104 / ASTM C-88), Sieve Analysis (AASHTO T-27 / ASTM C-136), Coating and stripping of bitumen (AASHTO T-82), Specific Gravity and Absorption Test (AASHTO T-85 / ASTM C-127), Unit Weight Test (AASHTO T-19 / ASTM C-29), flakiness and elongation of coarse aggregate (ASTM D-4791) and Petrographic analysis for AAR, ASR & ACR (ASTM C-295). Results of all tests are compared with international standards to ascertain the appropriateness of aggregate resource.

RESULTS AND DISCUSSION

Outcrop Geology: Palaeocene Khairabad limestone (the Lockhart limestone of Stratigraphic Committee of Pakistan) is well exposed and well developed throughout northern Pakistan including Western Salt Range, Kalachitta and Hazara areas (Gee, 1980; Afzal and Daniels, 1993; Shah, 2009; Munawar et al., 2022; Ali et al., 2023). In western Salt Range, it is excellently exposed in Namal Gorge and at Khairabad near Kalabagh Town. Khairabad lies 3Km east of the Kalabagh Town and about 45Km in the north of Mianwali Town. It is easily accessible from Mianwali via Mianwali-Kalabagh Road. At Khairabad, it is mainly comprised of light to medium grey and medium bedded limestone with minor marl and shale. Shale occurs in the basal part of the rock unit. Limestone is hard, tough and nodular. The nodule size varies from 3×2cm to 4×3cm. The nodule size is generally less as compared Eocene Sakesar limestone. Limestone is argillaceous at the lower part. It is frequently fossiliferous and contains abundant benthonic foraminifera at surface. Some marl horizons/partings also occur in between the limestone beds. The total thickness of limestone unit is estimated about 130m. Khairabad limestone conformably overlies the Early Palaeocene Hangu Formation, and is conformably underlain by Late Palaeocene Patala Formation.

Figure 3: (a) Outcrop surface of study area; (b) light grey nodular limestone; (c) jack hammer at limestone quarry; (d) bedded Khairabad Limestone.

Petrography: Petrographic analyses (ASTM C-295) of selected limestone samples were conducted using polarizing microscope to characterize mineralogy, texture and reactive components (if any). Results of petrographic analyses reveal that Khairabad limestone is mainly composed of calcite (97% to 98%) with subordinate dolomite, quartz, clay and iron oxide in minor amounts. Calcite is mainly present as carbonate dwelling organisms and micrite. Carbonate dwelling organisms are mainly large benthic foraminifera (Fig. 4 a, b & c) with Dasycladacean green algae (Fig. 4 e) and minor amounts of Planktonic foraminifera (Fig. 4 d). Large benthic foraminifera mainly include Miscellanea, Lockhartia, Operculina & Ranikothalia (Fig. 4 a, b & c). Broken shells with abraded margins are also found in appreciable amount which are indicative of reworking and wave action processes during the deposition of Khairabad limestone (Fig. 4 d). Quartz frequently occurs as sub-angular to sub-rounded detrital grains. It is frequently monocrystalline and fine in size. Quartz forms 1% to 2% of the rock. Dolomite is fine crystalline and constitutes less than 1% in some samples. Clay occurs in forms small yellow to yellowish brown fine aggregates and forms 0.3% to 0.5% of the limestone in some samples. Iron oxide occurs in form of specks and colorations and constitutes 0.5% of rock. Micro-stylolites of high to medium amplitude, hosting brownish iron oxide remains, are observed in some sections which represent diagenetic conditions (Fig. 4 f). Parallel to sub-parallel calcitic veins (Fig. 4 c & f) are indicative of tectonism during diagenesis of Khairabad Limestone. These veins appear reddish pink in stained thin sections. Negligible reactive components were observed, thereby, indicating that limestone samples were found non-deleterious. It would not involve in alkali silica and alkali carbonate reactions (ASR & ACR) if used with Ordinary Portland Cement or high alkali cements.

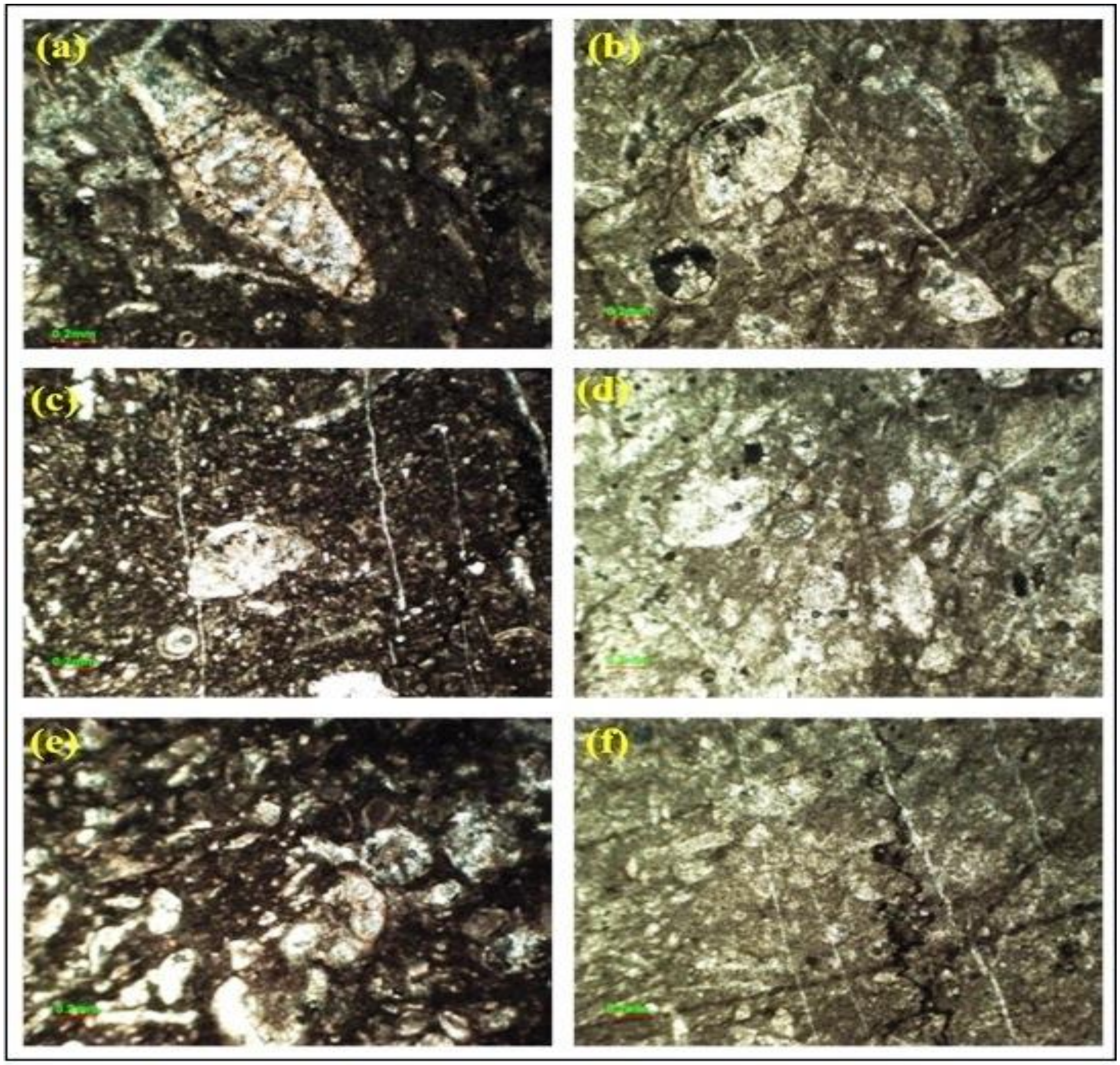

Figure 4: Photomicrographs of Khairabad Limestone showing distribution of larger benthic foraminifera Ranikithalia sp (a); Miscellanea sp. (b); Lockhartia, calcitic veins and fine quartz grains (c); broken bioclasts of Miscellanea, Bivalve and smaller foraminifera (d); micritic alteration of Dasycladacean algae and uniserial forams (e); stylolytes and calcitic veins (f)

Engineering Properties: AASHTO, ASTM, NHA and British Standard's designated several tests were carried out to evaluate various engineering properties of Khairabad limestone, such as: strength, abrasion, shape, bonding, weathering resistance etc. Results of these tests are discussed below:

i. Los Angles Abrasion Value (AASHTO T-96): This test was applied to determine the mechanical properties (toughness and abrasion) of aggregate. Los Angles percentage is calculated for each sample using following equation.

$$\text{Loss Angles \%} = W_1 - W_2/W_t \times 100$$

Where W_1 is weight of sample before test, W_2 is weight of sample after test, and W_t refers to the total weight. Result of this test is given in Table 1.

Table 1: Los Angles abrasion test of Khairabad Limestone

Sample No.	Weight before revolutions (A) Gram	Weight after revolutions (B) Gram	Net weight C=A-B	Los Angles % D=C/A×100	Average %
KLS-1	5000	3621	1379	27.58	
KLS-2	5000	3702	1298	25.96	
KLS-3	5000	3521	1479	29.58	26.59
KLS-4	5000	3789	1211	24.22	
KLS-5	5000	3774	1126	24.52	
KLS-6	5000	3614	1386	27.72	

According to AASHTO T-96, Los Angles percentage should be less than 40% for road base coarse, 35% for concrete and less than 50% for granular sub-base. Hence, Khairabad Limestone qualifies this test as the average value calculated (26.59 %) falls within the limit set by AASHTO T-96.

ii. **Aggregate Impact Test (IS: 2386 part-IV, 1993):** The Aggregate Impact Value (AIV) shows the capability of aggregate to resist crushing below gradual compressive load applied on it (Yaser et al., 2004; Al-Harthi, 2001). Lower the AIV, stronger will be the aggregate material (Mitchell, BGS). Impact value of Khairabad Limestone ranged from 11.7 to 15.69 with an average of 13.91 % which is pretty good for road projects. Result of each sample is given in Table 2.

iii. **Aggregate crushing value:** The aggregate crushing value (ACV) provides relative measures of resistance to crushing under progressively applied compressive load (Gondal et al., 2011; Khan and Chaudhry, 1991; ASTM 1998; BS 1989). According to AASHTO and ASTM, ACV should be less than 45%. Especially for concrete work it is kept below 30%. Average ACV of Khairabad limestone is 12.84 % (Table 3).

Table 2: Aggregate impact value of Khairabad Limestone

Sample No.	Weight of dry sample (A)	Weight passing No. 7 sieve (B)	Weight retained on sieve # 7	Impact value =B/A×100	Average %
KLS-1	466	60	406	13.45	
KLS-2	450	53	397	11.77	
KLS-3	446	70	376	15.69	13.91
KLS-4	417	59	358	14.16	
KLS-5	418	58	360	13.97	
KLS-6	426	61	364	14.43	

Table 3: Aggregate crushing value of Khairabad Limestone.

Sample No.	Weight before crushing (A) g	Weight after crushing (B) g	Crushing value % =B/A×100	Average %
KLS-1	3113	350.5	11.25	
KLS-2	3170	389.91	12.3	
KLS-3	3093.5	392.87	12.7	12.84
KLS-4	3540	503	14.2	
KLS-5	3418	465.5	13.6	
KLS-6	3390	441	13	

iv. **Soundness Test:** This is a durability test which measures the resistance to physical as well as chemical weathering. According to standards, soundness test value must be less than 12% for high quality aggregate (AASHTO, 2009; ASTM, 1998) and it depends on texture and mineralogy. Khairabad Limestone is a durable aggregate resource as its calculated soundness test value is very low i.e. averagely 1.84%.

Table 4: Soundness test of Khairabad Limestone

Sample No.	Passing	Retained	Weight of aggregate before test (A)	Weight of aggregate after test (B)	Loss C=A-B	Loss % D=C/A×100	Total Loss %
KLS-1	21/2”	11/2”	1098	1095.5	2.5	0.227	1.901
	11/2″	3/4″	950.5	948.3	2.2	0.231	
	3/4"	3/8”	655	650	4.5	0.687	
	3/8”	4”	300	301.7	2.3	0.756	
KLS-2	21/2″	11/2″	1025	1019	6	0.585	2.017
	11/2″	3/4″	870	867.3	2.7	0.310	
	3/4″	3/8″	632	629.1	2.9	0.458	
	3/8″	#4	301	299	2	0.664	
KLS-3	21/2″	11/2″	220	218.5	1.5	0.681	2.053
	11/2″	3/4″	307	305.7	1.3	0.423	
	3/4″	3/8″	293	291.3	1.7	0.580	
	3/8″	#4	298	296.9	1.1	0.369	
KLS-4	21/2″	11/2″	932	930	2	0.214	1.319
	11/2″	3/4″	765	763.5	1.5	0.196	
	3/4"	3/8”	416	414	2	0.480	
	3/8”	4”	303	301.7	1.3	0.429	
KLS-5	21/2”	11/2”	1004	1002	2	0.199	1.531
	11/2”	3/4”	913	911.2	1.8	0.197	
	3/4"	3/8”	353	351.5	1.5	0.424	
	3/8”	4”	281	279	2	0.711	
KLS-6	21/2″	11/2″	995	993	2	0.201	2.23
	11/2″	3/4″	628	626	2	0.318	
	3/4″	3/8″	387	384	3	0.775	
	3/8″	4”	266	263.5	2.5	0.939	

v. **Coating and stripping of bitumen (AASHTO T-82):** This method determines static immersion and coating retention of bituminous film on aggregate surface in presence of water. Coating and stripping value should be greater than 95% (AASHTO, 2009; NHA, 1998). Average stripping value calculated for Khairabad Limestone is 96.4% (Table 5) which is pretty good for asphalt purposes.

Table 5: Coating and stripping test of Khairabad Limestone.

Sample No.	Passing	Retain	Weight of sample (g)	Hot bitumen (g)	% Coating of aggregate after 24 hours
KLS-1	3/8”	1/4”	100	5.5	96.7
KLS-2	3/8”	1/4”	100	5.5	95.1
KLS-3	3.8”	1/4”	100	5.5	97.3
KLS-4	3.8”	1/4”	100	5.5	96.5
KLS-5	3.8”	1/4”	100	5.5	95.8
KLS-6	3.8”	1/4”	100	5.5	97.1

vi. **Specific Gravity and Absorption Test:** Specific gravity is analogous with the strength of aggregate, while high water absorption ability represents aggregate with low specific gravity. So the material having high specific gravity and low absorption capacity is recommended for use. AASHTO T-85 (2009) limits the standard value of specific gravity between 2.5 and 3, whereas absorption value between 0.1% and 2%. For

Khairabad Limestone, the mean value of water absorption and specific gravity is 0.83% and 2.7 respectively (Table 7).

vii. **Unit weight and voids in aggregate (AASHTO T-19; ASTM C29):** This method is primarily applied to determine the gradation and bulk density of geological materials (Chaudhary, 1991; ASTM, 1998; Khan, 2008). In this method, unit weight and void volume is calculated for compacted as well as loose condition. Mean unit weight of Khairabad Limestone is calculated as 1.649 g/cm^3 (Table 7).

viii. **Flakiness and elongation test of coarse aggregate:** This test defines shape of coarse aggregate. A fragment having large surface area w.r.t. its volume is considered elongated or flaky which decreases the durability and load bearing capacity of aggregate. Flakiness index is the percentage of particles with maximum dimension less than 0.6 times of their mean dimension. Whereas, elongation index is percentage by weight of particles whose greatest dimension is greater than 1 to 1.8 times their mean dimension. Both these tests are not applicable for particles smaller than 6.3mm. Maximum limit of elongation and flakiness set by ASTM (1998) is 15% to 25% with total index % (elongated + flaky) not more than 50%. Khairabad Limestone has average flakiness index of 10%, elongation index of 12.69% and total index of 22.78% (Table 6), which is significantly much lower than maximum limit.

Table 6: Total flaky and elongation index of Khairabad Limestone

Sample No.	Elongation index %	Flakiness index %	Total Index % = (elongated + flaky)
KLS-1	12.37	10.78	23.15
KLS-2	12.4	9.76	22.16
KLS-3	12.84	9.54	22.38
KLS-4	13.41	10.16	23.57
KLS-5	13.02	10.52	23.54
KLS-6	12.11	9.77	21.88

Table 7: Summary of engineering tests of Khairabad Limestone.

Test	Result (average)	Standard limit	Remarks
LA Abrasion Test	26.59%	Max. 40%	Suitable
Soundness Test	1.841%	Max. 12%	Suitable
Specific Gravity Test	2.7	2.5-3	Suitable
Water Absorption	0.83%	0.1-2.0%	Suitable
Coating and Striping	96.4%	Above 95%	Suitable
Unit Weight Test	1.649 g/cm^3	-	Suitable
Aggregate Crushing value	12.84%	< 30%	Suitable
Aggregate Impact Value	13.91%	-	Suitable
Plasticity Index	No Plasticity	Max. 4%	Suitable
Total (flakiness + elongation) index	22.78%	Max. 50%	Suitable
Petrographic Analysis	Suitable	-	Suitable

DISCUSSION

The outcrop investigations reveal that Khairabad limestone is dominantly comprised of hard and tough limestone except its basal part which is composed of minor shale and argillaceous limestone. The basal limestone is relatively incompetent with low strength and is not recommend for use as construction material whereas the physical outcrop characteristics of the remaining unit are apparently excellent to designate it as source for aggregate. The petrographic analyses of selected limestone samples from Khairabad limestone show that limestone is dominantly composed of carbonate dwelling organisms including Lockhartia, Discocyclina, Operculina and Ranikothalia with minor planktonic foraminifera which distributed over micritic groundmass. Among detrital constituents, it contains minor amounts of detrital quartz and clays (less than 1%). The limestone samples are frequently classified as Bioclastic wackestone and packstone. The petrography of limestone samples indicate that deleterious minerals are either absent or present in sluggish amounts which suggests that it is prone to ACR or ASR.

The results of engineering tests show that Khairabad limestone retains average Loss Angles Abrasion value of 26.59% which is significantly lower than maximum allowable limit of 40% as per ASTM and NHA specification which designate it as excellently competent material (Table 7). Similarly, the average soundness value is about 1.841% in comparison to maximum allowable limit of 12% which suggests that it is very resistant toward weathering and sulphate attack. In addition to this the average crush value (12.84%) and impact value (13.91%) of Khairabad limestone are also excellent as per ASTM and NHA specifications which are indicative of hard, competent, durable and high strength aggregate material. Similarly, average values of unit weight, water absorption, flakiness and elongation and bitumen coating and stripping etc. also fall within the permissible limits of ASTM, AASHTO and NHA which designate Khairabad limestone as excellent aggregate source for concrete and asphalt works. These values are further comparable with good quality aggregate of Pakistan as well as other than the Pakistan (Teme, 1991; ; Zarif and Tugrul, 2003; Tsikorous and Hatzipanagiotou, 2010; Gondal et al., 2012; Rehman et al., 2018).

Owing to its suitable mineralogical, chemical, physical and engineering properties, Khairabad Limestone is a good quality aggregate source for concrete, bound and unbound pavement, and also mortar. Furthermore, the Khairabad limestone is a well distributed in form of thick deposit (130m) in the vicinity of Kalabagh Town. The whole rock unit excluding the basal 6-7m of argillaceous limestone can be worked out for large scale aggregate preparation. Khairabad is easily accessible through Mianwali-Kalabagh Road and Daud Khel Railway Station which is about 5Km from Mianwali-Kalabagh Road which can be used to supply the aggregate in nearby areas.

Conclusion: Chemical, mineralogical, physical and mechanical properties of Khairabad Limestone revealed that it is a highly durable and suitable aggregate resource in Western Salt Range.

- Petrographic analyses depict that it is a compact limestone with no parting and very minute silica or dolomite. It has no ASR and ACR potential.
- Lower part of this reserve is slightly argillaceous which is to be avoided for aggregate mining.
- All results of engineering tests fall within specified limits of ASTM, AASHTO, BS and NHA which recommend it to be utilized in various construction purposes such as concrete mix design, mortar, bound and unbound pavement, road aggregate and buildings etc.

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