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Eocene Kohat Formation suitability as an aggregate from Kohat Range, Sub-Himalayas, Pakistan, based on outcrop, petrographic and geotechnical properties

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Abstract
This paper evaluates the physicochemical and mechanical characteristics of the Limestone of the Kohat Formation. The Eocene Kohat limestone is generally exposed in the Kohat, Hangu, and Bannu districts. Kohat Formation limestone is well exposed throughout the Northern Kohat fold and thrust belt at Togh Bala village. It is cream to grey, hard, compact, well-bedded and fossiliferous. Kohat Formation has been identified into two lithofacies which are from base to top calcareous shale lithofacies with large benthic foraminifera and limestone lithofacies. The faunal assemblage indicates that the Kohat Formation was deposited in an inner to middle shelf environment. The petrographic analyses of samples of the Kohat Formation depict that it principally consists of calcite (60-90%) with a small to trace assemblage of dolomite (0-3%), ungraded quartz (0-1.5%), opaque minerals (0-1.2%) and fossils (8-40%). Aggregate physical properties like water absorption (0.88%), specific gravity (2.69), soundness (2.55%), Los Angeles abrasion value (23.06%), aggregate crushing value (11.56%), aggregate impact value (12.68%), flaky index (9.90%), elongation index (12.76%) and coating and stripping values (96.27%) conform to available standards. Our results indicate that Kohat Limestone is safe in terms of Alkali Carbonate Reactivity (ACR) and Alkali-Silica Reactivity (ASR). The facies, thin section study, geochemical, and geotechnical understanding of Kohat Formation indicate that these aggregate deposits are potential aggregate sources for ballast (railway), road, building material, concrete, mortar and other mega projects for connecting Asia and Europe.

Keywords
Aggregate, mechanical, quartz, petrography, specific gravity.

Introduction

Carbonate rocks like limestone and dolomite are significant raw materials used in the construction and cement industries (Malkani, 2020; Sarfraz et al., 2021; Caserini et al., 2022). Tactical understanding of local and regional limestone resources for understanding their facies, physical, chemical, mechanical and mineralogical characteristics.

The aggregate is the major construction material used in the construction industry in projects like dams, highways, buildings and tunnels (Rehman et al., 2022). Aggregates are mainly derived from naturally occurring rocks, whether the rock is sedimentary, igneous or metamorphic. It may be obtained from the river bed deposits. The different sizes of aggregate are produced according to the different sizes of sieves used (Barksdale et al., 1991; Sims and Brown, 1998; Grieve, 2001; Smith and Collis, 2001). Aggregate is the main constituent of concrete using a suitable proportion of cement (Kosmatka et al., 2011). Aggregate economic significance, dimensional stiffness and resistance to wearing depend on its quality (Munir et al., 2016). Strength, porosity, mineralogy, specific gravity, and other characteristics of aggregates are carried over from the parent rock from which they were formed (Al-Oraimi et al., 2006). In Pakistan, there are major resources of aggregate to be used in the construction industry, but the sufficient usage of aggregate resources is going to be less, and it needs to explore more and more resources. Pakistan has tremendous resources of limestone used for construction purposes. Stupendous reserves of limestone rocks occur in Neoproterozoic, Cambrian, Permian, Jurassic, Paleocene, and Eocene all over Pakistan (Craig et al., 2018; Ghazi et al., 2015; 2020; Yasin et al., 2020; Ali et al., 2022a; 2022b; Rehman et al. 2022). The limestone aggregates are produced through rock quarrying and crushing in Punjab and KP's potential areas (Bilqees et al., 2015).

The belts of limestone are widely distributed in Kohat Range, Nowshera (Attock-Cherat Range), Hassanabal (Lesser Himalayan Range), Wah (Margalla Hills), Bet Kas-Khairabad- Dadu Khel (Salt range), Pezu (Marwat Range), Mughol Kot and Zindapir and many other localities in Pakistan (Shah, 1977; Rehman et al., 2022). The recent study refers to the fluid actions on aggregates of Kohat Limestone, their engineering properties, petrographic analysis, consumption and economic potential. Kohat Limestone is widely exposed in Kohat Hill Ranges or the upper Indus basin spread over a huge area.

There have been few studies on the stratigraphy and sedimentology of the Kohat area (Fig. 1). However, the aggregate potential is still less documented.

The objective of this study is the following:

1. To understand the facies types of Kohat Formation.
2. To link those facies to petrographic textures.
3. To decipher the link of physical properties with the facies and microscopic observations.

Geological Setting

The current area of interest is a segment of Kohat Fold and Thrust Belt (KFTB), located in the western boundary of the lesser Himalayas and characterizes the southwestern boundaries of the Himalayan belt in Pakistan (Abbasi, 1991; McDougal and Husain, 1991; Khalid et al., 2012; Wahid et al., 2022; Ghazi et al., 2015; 2020; Ali et al., 2022a). The main boundary thrust limits the KFTB to the north and south by the younger Bannu basin and Surghar Range. Potwar plateau and strike-slip Kurram fault form the eastern and southern extremity of Kohat fold and thrust belt, correspondingly. Several deformational episodes have occurred after the continent-continent collision of India and Eurasia (Zaib et al., 2021; Wahid et al., 2022). The sedimentary sequence of KFTB preserves the imprint of different deformational phases resulting from the collision of two tectonic plates with terminal stages during the Eocene (Abbasi, 1991; Ali, 2009; Ghazi et al., 2015; 2020; Javed et al., 2021; Ali et al., 2022b).

The structural style of the Kohat Fold and Thrust belt and adjacent NPDZ represent intense deformational history as compared to the rest of the Potwar Plateau (Abbasi, 1991; McDougal and Husain, 1991). The study area located in the Kohat district tectonically forms part of the northern Kohat fold belt. The stratigraphy of the study area is given in Fig. 2. The stratigraphy of northern Kohat folds and thrust belt comprises Eocene Bahadur Khel Salt and Jatta Gypsum, the older rock units exposed in the study area. Kuldana and Kohat formations are overlaid by evaporite deposits (Yasin et al., 2021). Miocene Kamlial Formation is overlain by Kohat Formation (limestone). The evaporitic and carbonate sequence of the northern Kohat fold and thrust belt is overlain in turn by the Siwalik Group, i.e., Chinji and Nagri Formation (Meissner et al., 1974; Wahid et al., 2022).

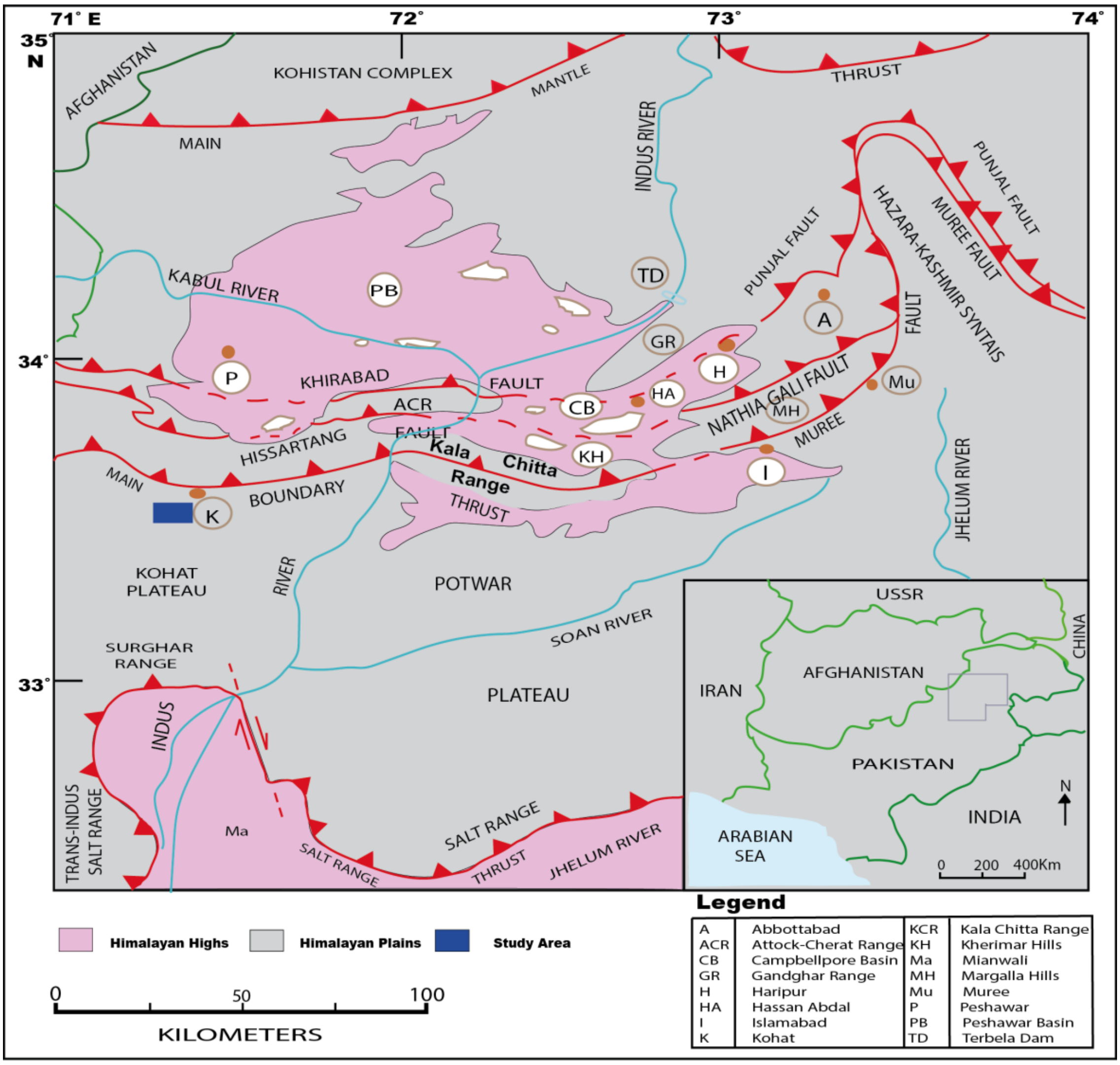

Fig 1: Map showing study area (Highlighted) modified after (Kazmi and Rana 1982).

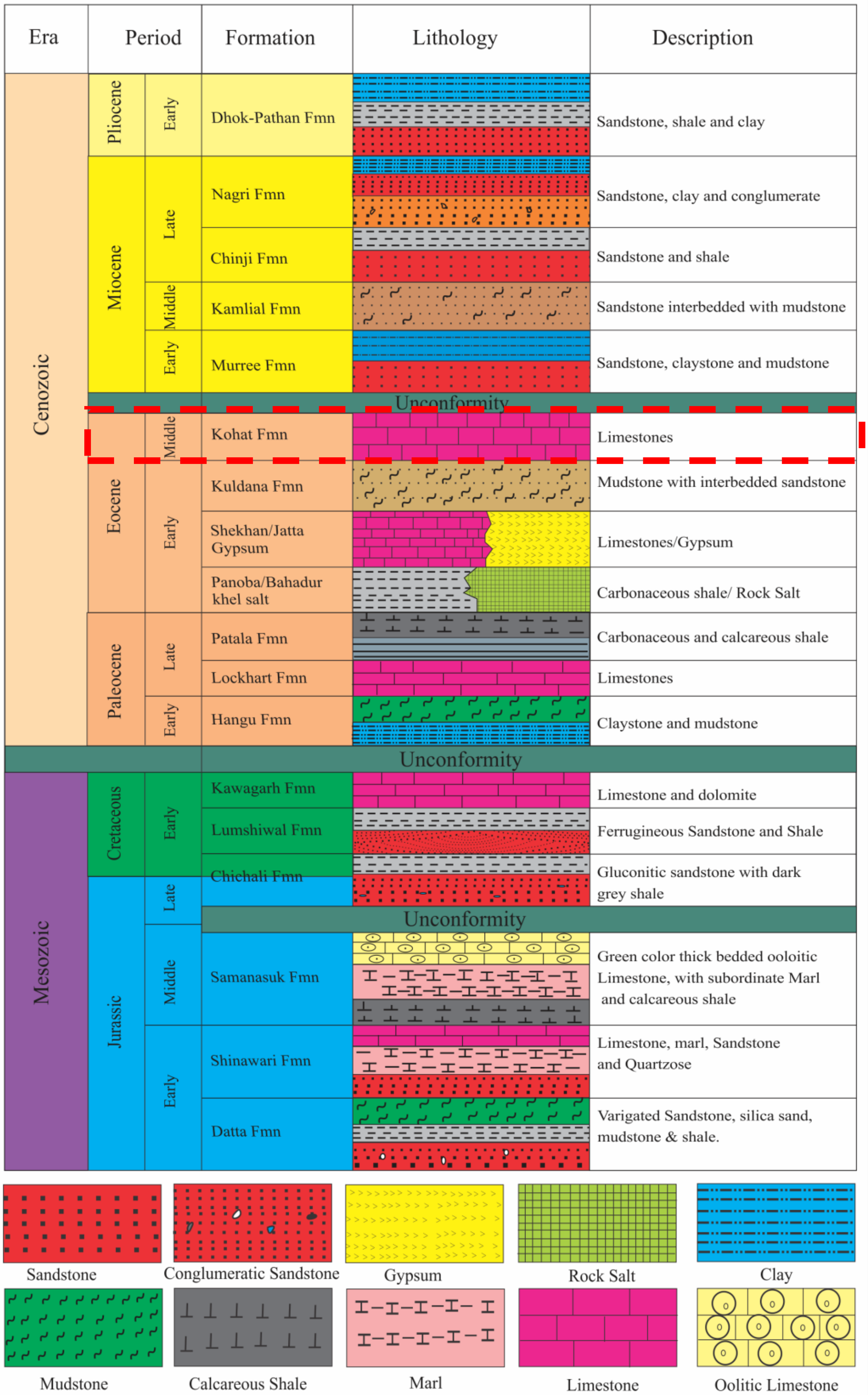

Fig 2: Stratigraphic framework of the Kohat plateau showing study of Kohat Formation (Modified after Meissner et al., 1974).

Material and Methods

Field Investigation

For aggregate selection, fieldwork is a very important tool for determining the engineering and in-situ properties of rocks, including colour, texture, bed thickness, mineralogical composition and lithology, etc. In the present study, exclusive fieldwork was carried out, and Limestone samples were collected from various localities in the Kohat fold and thrust belt (Togh-bala, Sheikhan Nala and Jarma area). The selected sections for the current study are near Kohat Rawalpindi link road. The study area can be easily accessed from Bannu, Karak and Peshawar through a network of metallic roads. Togh-bala section is situated on Rawalpindi Road, about 5 km from Kohat bypass. To examine the physical property of aggregate, each sample was labelled according to its location, quarry, naming and source.

Laboratory Testing

Engineering and geological properties of aggregate material is the main tool used for the quality assessment of natural and crushed rock for engineering use. These properties are evaluated through laboratory testing design by different international agencies and societies like AASHTO, ASTM, BS and NHA. Thin sections of Kohat limestone were prepared according to ASTM C295-90. These thin sections were studied with a polarized microscope to evaluate the chemistry of the aggregate. Aggregate characterization and relationship with asphalt, cement and concrete were studied according to BS, AASHTO and ASTM standards.

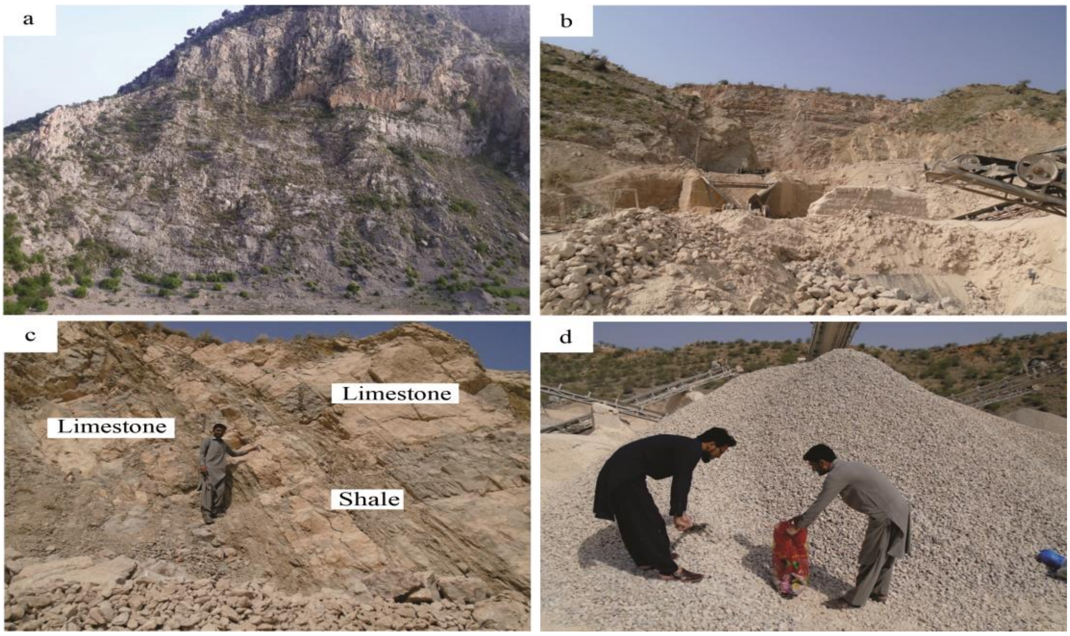

Fig 3: a. The outcrop view of Kohat Limestone. b. Showing the crushing activities in the study area. c. Showing thin to thickly bedded limestone of Kohat Formation. d. Collection of mixed aggregate samples from the jaw crusher.

Results and Discussion

Lithofacies

The data was obtained for lithofacies analysis from the outcrop of the Kohat Formation, Kohat area. This included section measurement with the observation of lithology and marking different lithofacies. Generally, the Kohat Formation is comprised of limestone and shale. It is comprised of nodular limestone with subordinate shale and marl partings. Kohat Formation has been measured in Togh Bala and Jarma Sections. The Kohat Formation is of the Middle Eocene age in Kohat Range, Sub-Himalayas (Fig. 1). The total thickness of the Kohat Formation in the Togh Bala and Jarma Sections is 125m and 105m, respectively. The bedding style of Kohat Limestone is medium to thick-bedded in the study area. Thick bedded limestone has constructional significance because, for quarry selection, it provides more quantitive production, and the aggregate is devoid of flakiness and elongation. The Kohat Formation in the study section is well exposed with its lower conformable contact with Kuldana Formation and upper contact with Muree Formation, which is unconformable and demarcated by MBT (Main Boundary Thrust).

Two Lithofacies have been observed in the field, which are Limestone facies and calcareous shale facies. The Limestone facies comprise the topmost part of the formation and are composed of predominantly limestone, which is cream and grey in colour, hard, compact and well-bedded.

Calcareous Shale facies comprise the middle and lowermost part of the formation and consist of greenish-grey carbonaceous shale with a minor amount of light-grey limestone and abundant benthonic foraminifera. The petrographic study suggests that it contains larger foraminifera (Nummulites beaumonti d'Archiac & Haime, Nummulites mamillatus (Fichtel & Moll), Assilina exponens (Sowerby), Alveolina elliptica), crinoids and echinoids (Mirza et al., 2005).

Petrographic Analysis

Petrographic analysis (Nixon and Sims, 2006) was carried out for the aggregates, which are used to examine their micro-textural, diagenetic feature, and chemical and mineralogical categorization. The petrographic analysis revealed that limestone is mainly comprised of skeletal grains, including Nummulites, Alvolinoid and Assilinids. However, trace fauna was also encountered in the limestone of Kohat formation, including crinoids, echinoids, broken algae and broken bioclasts. Non-skeletal grains were also observed as quartz and partially dolomitized grains under thin sections. The outer groundmass of all the skeletal and non-skeletal grains largely consists of a micritic matrix.

The presence of calcite amount in the studied thin section is about (40 to 90%). Fine to medium-grained patches of calcite is found in various section of the studied sample. Quartz is present in the Eocene Kohat limestone at a minor amount maximum of up to 1.5%. It is found in the study section in the form of subhedral medium-grained, detrital material disseminated through the rock. Kohat Formation has undergone a variety of diagenetic processes, including micritization, neomorphism, cementation, fracturing, and dolomitization. Broken micrite envelops, deformed grains and grain-to-grain sutured contact are evidence of mechanical compaction. In grain-dominated facies, the broken shells and the interior portion of tests are filled with calcite, and in some cases, the whole tests of fossils are replaced by sparry calcite cement or micrite, which are considered pseudo fossils (Fig. 3b). Calcite cement can also be observed in thin section in the form of calcite patches and calcite filled veins (Fig. 3b). The presence of microscopic envelopes in some microfacies (Fig. 3e) suggests that slow sedimentation rates during deposition to sustain microbial activity for a longer period in shallow marine conditions. Dolomite is a well-preserved fabric commonly associated with calcite veins and is considered a secondary phase. Dolomites are found in studied thin sections in trace amounts (Tab. 1).

Fossils of the Kohat Formation are dominated by foraminifers, and different species of Alveolina, Assilina, Nummulites, and Algae are recorded from the formation in the area of research. The quantitative distribution of the larger benthic foraminifers and smaller planktonic foraminifers helped us to construct the depositional setting of the Kohat Formation. The high ratio of larger benthic foraminifers and a low ratio of planktonic foraminifers in the studied sections suggest deposition in low to moderate energy conditions on the inner to middle shelf setting.

Tab. 1. Petrographic analysis of Eocene limestone of Kohat Formation.

Sample no.	Calcite	Fossils	Dolomite	Clay	Quartz	Opaque mineral
KLZ1	85	10	2	1	0.8	1.2
KLZ2	90	8	1.5	0.5	Trace	0
KLZ3	80	15	3	0	1.5	0.5
KLZ4	90	10	Trace	0	Trace	0
KLZ5	60	40	0	0	Trace	Trace
KLZ6	75	25	Trace	0	0	0

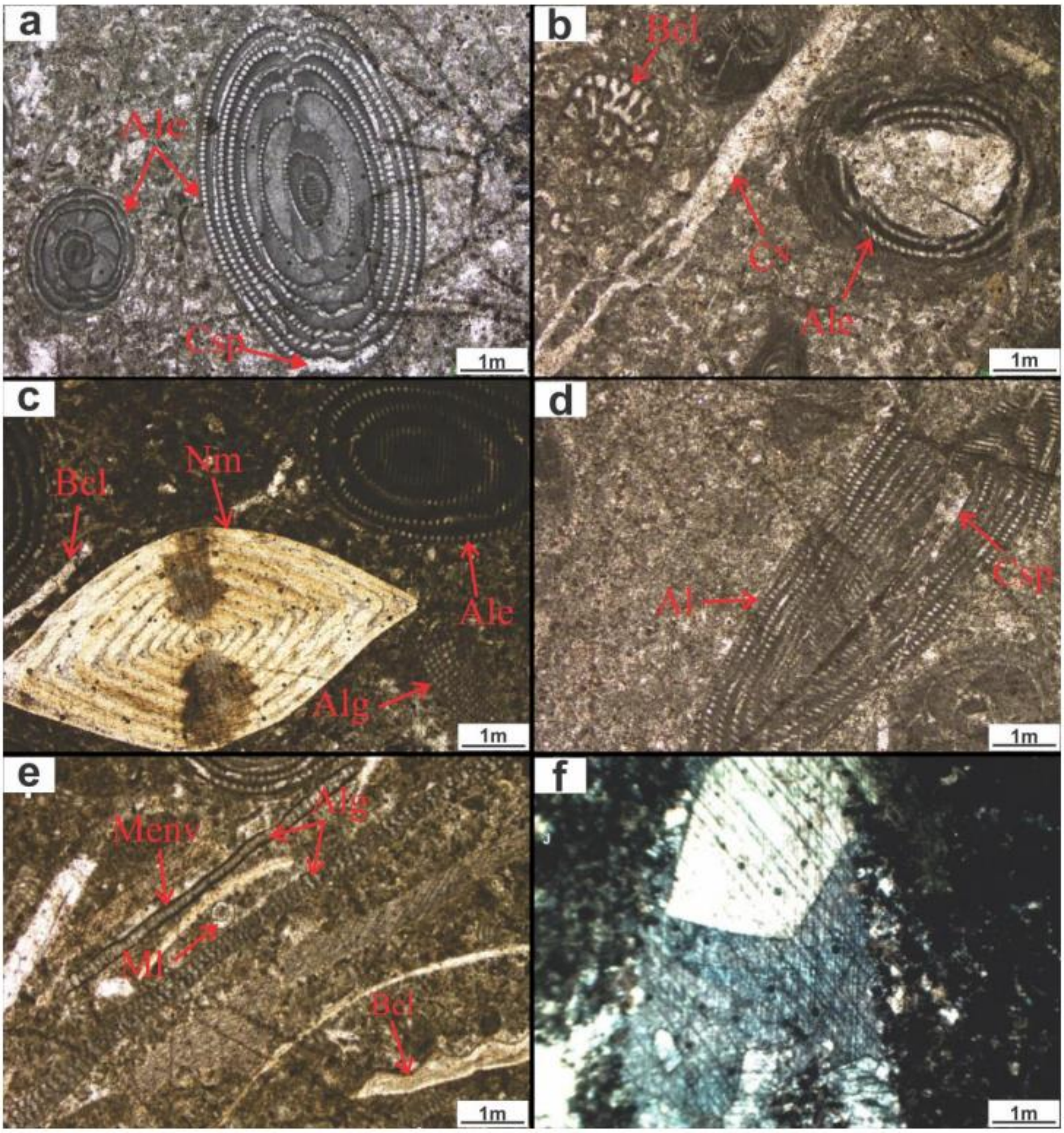

Fig 4: (a) Photomicrograph of Kohat Limestone showing Alveolina elliptica (Sowerby) (Ale), having outer chamber replaced by sparry calcite (Csp). (b) Photomicrograph showing Alveolina (Ale), broken bioclast (Bcl), large calcite-filled vein (Cv), and rounded to sub-rounded grains of quartz disseminated with the fine-grained calcite matrix. (c) Photomicrograph showing shows an equatorial view of Nummulites beaumonti (d'Archiac & Haime) (Nm), green algae (Alg), Alveolina (Al) and broken bioclast (Bcl). (d) Photomicrograph illustrating alveolina species (Al) having inner chamber replaced by sparry calcite (Csp). (e) Photomicrograph showing Miliolids (Ml), green alga (Alg) and broken microfossils tests (Bcl) embedded in a fine-grained calcite matrix (f) Some zoned dolomite crystals.

Los Angeles Abrasion Test (AASHTO T-96)

LAB value determines the toughness behaviour of aggregate endure natural and stressed conditions. The toughness of aggregate is determined by its resistance to disintegration and degradation under physical and chemical conditions (Neville and Brooks, 1987; Gondal et al., 2009). Resistance of aggregate to abrasion is the key aspect when used in a structure like concrete pavements, and roads constantly remain under heavy load (Smith and Collis, 1993). The study sample of all zones has an abrasion value below the maximum specified limits. The abrasion value should not exceed 35% and 50% for aggregate use in concrete and road works (NHA, 1991; AASHTOO, 2009). The value of abrasion varies from 24.7% (KLZ-1) to 20.6% (KLZ-6), with an average value of 23.06%, which is within the safe limit to use as an aggregate for road and concrete works.

Aggregate Impact Values Test (IS., 2386 (Part IV) – 1963)

Aggregate impact values evaluate the performance of aggregate to impulsive load and stress. The aggregate of lower strength can be degraded when subject to sudden impact load. The competence of source material is the key indicator of hard and good strength aggregate. The impact value is an essential indicator of good quality aggregate (Ahsan et al., 2009). In the present work, the maximum impact value of 15.69% was recorded in KLZ-3 (Tab. 2). The average value for Kohat limestone aggregate is 12.68% which is well safe in limits as per the value specified by international societies of ASTM, AASHTOO and NHA.

Crushing Value Test (ASTM C-131)

The crushing value is evaluated to find the strength behaviour of aggregate under gradually applied compressive force by vehicle load (AASHTOO, 1990). Low-strength aggregate decreases the performance and quality of aggregate. The crushing value for aggregate to use in concrete and road work should be less than the maximum value of 30% as specified by international agencies (ASTM, 2004; AASHTOO, 2009) and 22.5% (NHA,1998). In the current study, the crushing value ranges from 9.54% (KLZ-2) to 13.66% (KLZ-5), which is well below the maximum allowed value.

Soundness Test (AASHTO T -104)

The soundness test is designed to calculate the degree of disintegration and degradation of geological material exposed to different weathering conditions (AASHTO, 2009). The aggregate material should be resistant to degradation against several surficial weathering conditions of thermal changes, freeze and thawing effect and the effect of salt minerals within pores of particles (Bloem, 1966, Wu et al., 1998; Kazi and Al-Mansur, 1980). The geological material is avoided use as aggregate that are susceptible to weathering effect to minimize the failure of the structure during field condition (Gondal et al., 2009). In the studied samples, the maximum value of 3.42 was recorded for KLZ-6 and a minimum value of 1.90% was observed in KLZ-1 (Tab. 2). The average value of soundness is about 2.55% which is much lower than falls within the safe limit as specified.

Specific gravity Test of Coarse Aggregate (AASHTO T- 85)

The specific gravity of a material is the ratio of the weight of the sample to the given volume of water. It is the physical property of aggregate that is used to calculate the strength and quality of aggregate (Smith and Collis, 1993). Absorption value is used to assess the void spaces between mineral grains of aggregate. The aggregate of high absorption value designates Poor quality and low strength aggregate and avoids using in structure experience diverse loads. In the current study, the specific gravity value ranges from 2.54 (minimum) to 2.76, with a mean value of 2.69 for Kohat limestone aggregate. The absorption value is indirectly obtained from specific gravity that varies between 0.60 (KLZ-4) to 1.38 (KLZ-3). In a recent study, the absorption value is lower than the maximum 2.5 allowed value.

Flaky and Elongation Test (BS-812)

The test is designed to calculate the portion of flat and elongated particles in the aggregate mix (Hartly, 1974), which causes a serious problem during compaction and infield performance of aggregate base structure (Salih and Sravana, 2013). A good quality aggregate is free of flat and elongated particles that enhance the strength and workability of concrete and road works (Molugaram et al., 2014). The flaky and elongation index in the current study is below 15%, which is the maximum allowed range (NHA, 1998). The flaky index varies from 8.68% for KLZ-6 to 10.78% for KLZ-1, whereas the elongation index is recorded between 11.46% for KLZ-6 to 13.48% for KLZ-2. The average value of flakiness is 9.90%, and elongation is 12.76%.

Coating and striping of bitumen (AASHTOO T-82)

This test is manually performed in laboratory conditions to observe the coating and adhesion capacity between aggregate and bitumen (Kazi et al., 1980; Gondal et al., 2009). Coating of bitumen to aggregate is a surface phenomenon that mainly rests on the properties of geological material (Tarrer and Wagh, 1991). The aggregate-to-bitumen bond should be strong enough to resist striping, which is a prerequisite to increasing the infield performance of asphalt mix roads (Jamieson et al., 1995). In the present study, the Aggregate bitumen's coating percentage remains above 95% (NHA, 1998), with the highest value of 97.3% recorded in KLZ3.

Tab. 2. Engineering properties of Kohat Limestone.

Name of Test	Sample Number						
	KLZ1	KLZ2	KLZ3	KLZ4	KLZ5	KLZ6	Mean
Specific Gravity	2.72	2.70	2.76	2.71	2.74	2.54	2.69
Water Absorption Test	0.72	0.68	1.38	0.60	1.20	0.71	0.88
Sulphate Soundness Test	1.90	2.02	2.04	3.03	2.89	3.42	2.55
Los Angles Abrasion Test	24.7	23.3	21.1	24.2	24.5	20.6	23.06
Aggregate Crushing Value	10.82	9.54	11.56	11.00	13.66	12.78	11.56
Aggregate Impact Value	11.16	8.81	15.69	14.16	13.97	12.34	12.68
Flakiness Index	10.78	9.76	9.54	10.16	10.52	8.68	9.90
Elongation Index	12.37	13.48	12.82	13.40	13.06	11.46	12.76
Coating and Striping	96.78	95.14	97.36	96.54	95.80	96.0	96.27

Discussion

Physical properties are mainly the study of the behaviour of the aggregate, which is widely used in concrete, roads, etc. (Neville and Brooks 1987). Specific gravity is a measure of rock density that determines rock strength. The higher the specific gravity, the larger the common binding of its ingredients will be and hence the greater force required to rupture them separately. Rocks having specific gravity >2.55 are measured properly for profound construction workings (Blyth and de Frietas, 1974). The average value of the specific gravity of Kohat Limestone is 2.70 to 2.74. The resulting values occur within the range of AASHTO specification, which is suitable for overall construction purposes. The absorption value of studied samples varies from 0.60 to 1.38 %. These values indicate that the aggregate sample has low effective porosity. The soundness test helps measure the weathering and erosion process on the aggregate. The soundness test results range from 1.90 to 3.03%, which is according to National and International standards. Therefore Kohat Limestone is sound and resistant to chemical weathering and erosion, so it is suggested that the studied sample is good for base and sub-base uses.

The Los Angeles values of Kohat Limestone obtained from the laboratory test vary from 20.6 to 24.7%. The values come within specific limits, indicating that Kohat Limestone is acceptable for road and concrete structures. Aggregate crushing value values of the sample range between 9.54 to 13.66%. According to International standards, the aggregate crushing values should be less than 35% for the utilization in road construction. Aggregate impact value is used to measure the toughness of Aggregate. The values of AIV range between 8.81 to 15.69% for the base course and sub-base. The AIV is not more than 30% according to BS and ASTM standards, so the result shows that the aggregate is excellent for all types of construction purposes. The coating and stripping test is used to determine the adhesiveness of the bituminous layer on the aggregate shallow in the moisture content. The coating and stripping value of the studied sample is greater than 95%. Therefore, it is applicable to the construction of flexible pavements.

Petrographic identification plays an important role in determining deleterious constituents in aggregate. Petrography determines the extent of weathering condition of an aggregate. It is used in the construction industry for alkali-aggregate reactive constituents. According to ASHTO (C 29590), the following constituent is capable of alkali-silica reaction in cement concrete, Quartz veins, chert, tridymite, opal, schist, gneiss and sandstone. The important causative agent for alkali carbonate reaction is calcareous dolomite and clay insoluble residues. Petrographic studied samples of Kohat Limestone show that there are no deleterious agents which cause ASR (Alkali silica reaction) and ACR (alkali–carbonate reaction) or any physical change in the concrete structure.

Conclusion

Kohat formation is well exposed at Jarma and Togh Bala sections and is mainly composed of dark to grey limestone and interbedded shale. The overall thickness of Kohat formation at the Jarma section is about 105 meters and varies in thickness at the Togh Bala section up to 125m. Field investigations show that the lower part of the Kohat Formation contains light grey compact limestone with thin-bedded shale in the lowermost part. From west to east, it becomes thick-bedded. The middle part of the Kohat formation is composed of grey to greenish shale, interbedded limestone with abundant benthonic foraminifera. The upper part of the formation comprised of thick to massive bedded cream colour limestone with very few marl partings. Petrographic examination revealed that Kohat Formation shows abundant larger benthonic foraminifera, which indicates an inner to middle shelf depositional environment. Different diagenetic processes, such as cementation, physical and mechanical compaction, micrization, fracturing, neomorphism, and dolomitization, were seen in the Kohat Formation. The average values of the laboratory test, i.e. Soundness test, Aggregate Impact Value, Crushing value, loss Angeles, specific gravity, water absorption, Coating and striping value, flaky index and elongation index, respectively, are under the specification of NHA, ASTM and BS standards, so the studied Limestone in the selected section at Kohat plateau is acceptable for the construction industry. From the above test results, it is concluded that the Kohat limestone in the studied section falls within the National and International specifications, so a good aggregate for the concrete, base course, sub-base, and construction of pavements and buildings is recommended. The petrographic examination result shows that the limestone of the Kohat Formation is non-deleterious/ destructive because no reactive component was observed, so it is useful in cement concrete.

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