

Investigation of Physico-Mechanical Properties of Kohat Limestone at Sur-Dag and adjoining Areas, Khyber Pakhtunkhwa, Pakistan

Nazir-ur-Rehman¹, Mumtaz Ali Khan^{2*}, Afrasiab¹, Ishtiaq Zaman¹ and Khalid Khan³

¹ Department of Geology, Khushal Khan Khattak University, Karak, Pakistan

² Department of Earth & Environmental Sciences, Bahria University, Islamabad, Pakistan

³ Geological Survey of Pakistan

*Corresponding Author: mumtazkhan@bui.edu.pk

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Abstract

This research study was conducted to assess the suitability of the Kohat Limestone from the Sur-Dag section as a construction aggregate for civil engineering purposes, utilizing geological laboratory testing. Limestone aggregates are essential components in both small and large-scale civil works projects, including pavements, buildings, bridges, roads, and dams. In addition to being produced from synthetic materials like slags, aggregates are derived from natural materials, including rock, sand, and gravel. The use of these aggregates in any project depends on their engineering properties. These engineering properties should meet the specified standard designated by different organizations like the American Association of State Highway and Transportation Officials (AASHTO), the American Society of Testing and Materials (ASTM), and the British Standards (BS). Laboratory tests were conducted in accordance with these standards to evaluate various parameters of the Eocene Kohat Formation, including specific gravity, water absorption, Aggregate Crushing Value (ACV), Flakiness Index (FI), Elongation Index (EI), Los Angeles Abrasion value (LAAB), Aggregate Impact Value (AIV), as well as coating and stripping values. The Formation is well developed and exposed in the Southern Kohat Basin. At the outcrop level, the color is cream to gray, well-bedded, compact, hard, and rich in fossils. The values of all engineering properties of the samples fall within the acceptable standard ranges. Therefore, this research provides reliable data regarding the suitability and availability of the Kohat Limestone as a construction aggregate in this region. This study concludes that the Kohat Formation is suitable to be used as a sub-base, base course, and concrete aggregates for the construction of buildings and pavements.

Keywords: Kohat Limestone; Aggregate; Physio-mechanical properties; Southwestern Kohat Basin; Engineering properties

1. Introduction

The study area is located in the southwest part of the Himalayan foreland fold and thrust belt, at 32° 46' 12.07" and 33° 22' 10" North and 70° 43' 17.05" and 71° 33' 10.03" East, known as Kohat Basin (Figs. 1-2). During the Miocene, Kohat Basin became the center for the deposition of sediments that were eroded from the main Himalayas, which deformed and uplifted in the form of a foreland fold and thrust belt (Ahmed, 2003; Rehman et al., 2024). Eocene to Pleistocene age rocks are exposed in this area, comprising evaporates,

limestone, clays, and sandstone. The southern part of the Kohat plateau is covered by evaporates, which are the basal rocks of the Eocene in this area, and the northern part is composed of shale (Ahmed, 2003; Rehman et al., 2022a).

The Kohat Formation, primarily composed of light grey to cream color massive to nodular limestone with marl and green shales, has been previously studied for its depositional environments, diagenetic features, and reservoir potential (Paracha, 2004; Iqbal et al., 2016; Khan et al., 2018). Some studies suggest that this formation

may serve as a potential hydrocarbon reservoir due to its porosity and permeability variations (Kazmi and Rana, 1982; Jan et al., 2019). Moreover, research on the engineering properties of Kohat limestone has highlighted its applications in construction materials, particularly as an aggregate source (Rehman et al., 2020; Gul et al., 2021).

Aggregate denotes the natural or crushed stone material used for construction purposes. Aggregates are generally characterized on the basis of different mechanical and geological properties, and materials with definite quality and engineering properties are used for specifically designed structures. The quality of aggregate is ensured by testing, regarding its various properties such as abrasion, its behavior towards solutions, and shape. The lithology and grain-size arrangement define the quality of an aggregate regarding its physical, chemical, and mechanical properties (Yoon and Tarrer, 1988; Kandhal et al., 2000). In flexible or rigid pavements, the behavior of aggregate is mainly regulated by factors like abrasion,

soundness, and shape orientations (Fookes et al. 1988; Lafrenz, 1997; Neville, 2004). Aggregates are generally produced by the crushing of intact rocks exposed at the surface by means of mining and crushing. In sedimentary rocks, limestone is more frequently used source for the preparation of aggregates.

In Pakistan, good-quality limestone sources are widespread, specifically in the different parts of the Himalayan fold and thrust. The presence of large quantities of Eocene Kohat limestone in the district of Karak owes its uses for different purposes, including construction. Previous studies have evaluated its mineralogical composition and geotechnical properties. However, a detailed study of the Kohat limestone in the Karak region that assesses its suitability as a structural foundation stone has not been established yet. Therefore, the emphasis of this study is to illustrate all the major physico and petrographic properties of the Kohat limestone to check its suitability as a foundation stone.

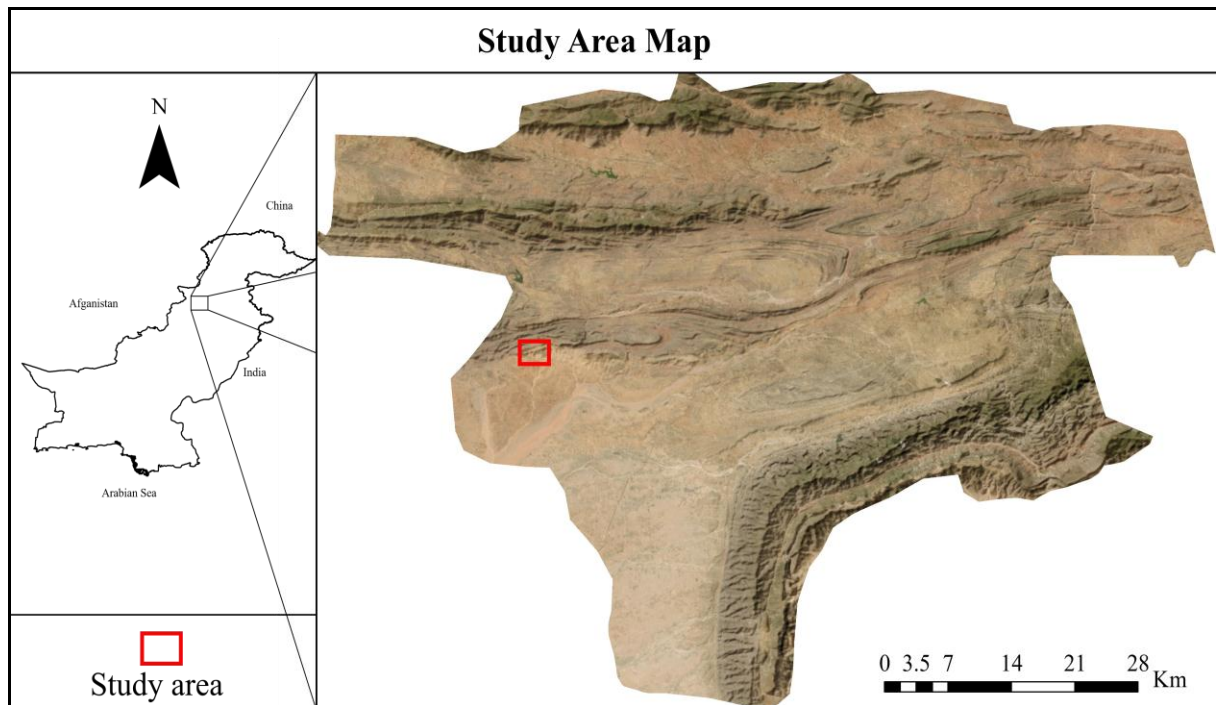


Fig. 1. Location map of the research area.

2. Ecological Setting

The ongoing collision between the Indo-Pakistani Plate and the Eurasian Plate since the Eocene epoch has played a crucial role in shaping the compressional thin-skinned tectonic structures along the northern and northwestern margins of the Indo-Pakistani Plate. This prolonged subduction, which began in the Cretaceous period, contributed to the development of the Himalayan orogenic belt and the formation of a series of foreland basins segmented by extensive fault networks (Abbasi and McElroy, 1991; Rehman et al., 2022b). Among these, the Kohat-Potwar

thrust-fold belt stands out as a significant geological province, well-known for its hydrocarbon potential. This belt is structurally divided into the Northern Potwar Deformed Zone, Salt Range, Kohat Plateau, Bannu sub-basin, and Trans-Indus Ranges (Kazmi and Rana, 1982) (Fig. 2). The northern foreland basin is extensively deformed and extends southward from the Main Mantle Thrust, whereas the southern deformed foreland basin, which encircles the Himalayan Mountain belt, stretches from India's Ganges Delta to Pakistan's South Waziristan Agency (Rehman et al., 2017) (Fig. 2).

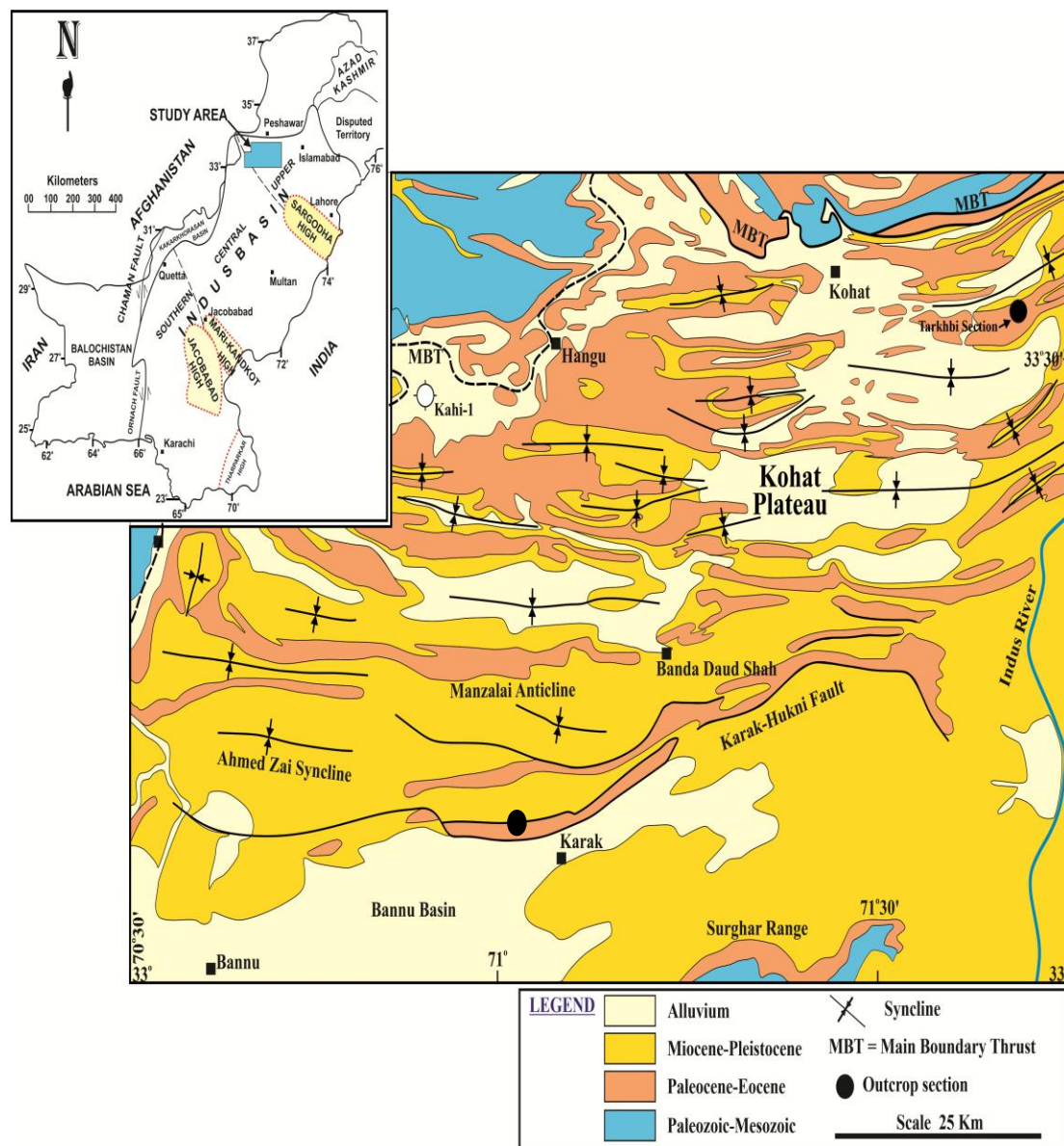


Fig. 2. Geological and tectonic map of Pakistan depicting the tectonic features of the northwestern Himalayan foreland fold and thrust belt (after Pivnik and Wells, 1996).

The Main Boundary Thrust (MBT) serves as a major tectonic boundary that separates the northern and southern structural domains of the fold and thrust belt (Rehman et al., 2016).

The Kohat Basin, located in the northwestern segment of the Himalayan foreland, became a primary depositional center for synorogenic sediments from the early Miocene onward. It forms the western part of the Indo-Gangetic foreland basin, with sedimentary sequences ranging from the Paleocene to the Pliocene epochs (Fig. 2). The oldest Paleocene rocks in this basin were deposited in a restricted marine foredeep setting influenced by the tectonic loading along the Indian Plate's margin. Over time, these deposits were overlain by a thick succession of evaporites, carbonates, shales, and clastic rocks, indicating the complex interplay of marine and continental depositional environments (Pinvik and Wells, 1996). This stratigraphic succession reflects the evolution of the Kohat Basin as a structurally isolated remnant of the Tethys Ocean, situated between the southern Asian margin and the northwestern Indian continental margin.

The stratigraphy of the southern Kohat Basin is characterized by three distinct lithostratigraphic units spanning different geological periods: the Eocene, Miocene, and Plio-Pleistocene sequences (Rehman et al., 2022b) (Fig. 3). The Eocene sequence is composed of the Panoba Shale and Bahadur Khel Salt at its base, followed by the Jatta Gypsum, Mami Khel Clay, and the Kohat Formation. These formations collectively illustrate the paleoenvironmental conditions and depositional processes prevalent during the Eocene. Overlying the Eocene deposits, the Miocene-age rocks of the Rawalpindi Group, predominantly represented by the Kamli Formation, consist mainly of clastic sediments, providing insights into the basin's fluvial and deltaic depositional settings during this epoch. The youngest stratigraphic unit, the Plio-Pleistocene sequence, corresponds to the Siwalik Group,

which consists of thick molasse sediments derived from the erosion of older rock formations. This group includes the Soan, Dhok Pathan, Nagri, and Chinji formations, which serve as key indicators of past climatic conditions, landscape evolution, and regional tectonic activity during the Plio-Pleistocene (Fig. 3).

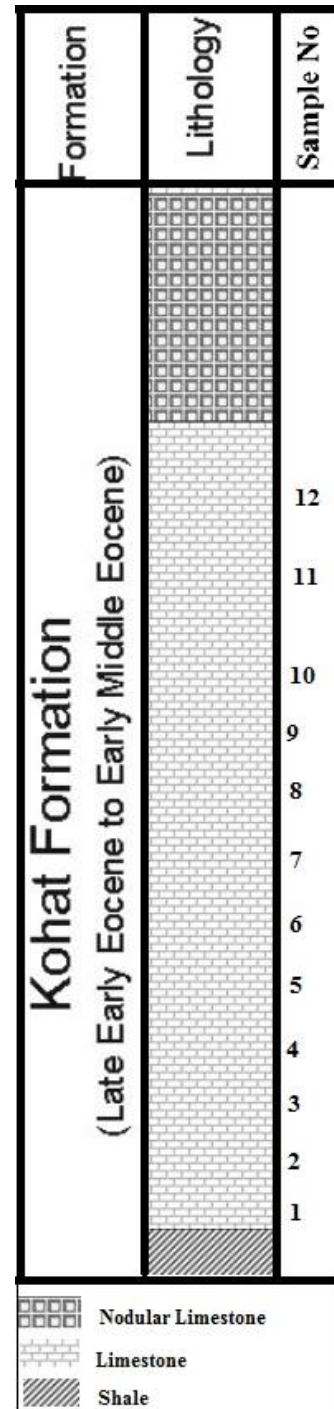


Fig. 3. Lithological column of the Kohat Formation (study area).

A detailed stratigraphic framework, developed using data from drilled wells across the Kohat Basin, reveals significant variations in thickness and facies distribution from east to west. These lateral variations highlight the influence of tectonic movements and differential subsidence on the deposition and preservation of sedimentary units over time. Understanding these spatial differences is crucial for evaluating the hydrocarbon potential and geotechnical characteristics of the region. The integration of stratigraphic, structural, and sedimentological data provides valuable insights into the geological history, resource distribution, and tectonic evolution of the Kohat Basin.

3. Materials and Methods

The methodology of the current research work includes field and laboratory work. The Sur-Dag section of the southwestern Kohat Basin was selected for the sampling of the Eocene Kohat Limestone. The characteristic features, i.e., lithology, texture, grain size, color, bedding pattern, thickness, fauna, lateral extension, etc., were recorded to find out the geological suitability, workability, and economic potential. A total of 12 samples were collected from the formation for the determination of the physico-mechanical properties. All the samples were studied under the petrographic microscope. The collected samples were subjected to the different geotechnical tests, i.e., specific gravity, water absorption, flakiness and elongation tests, crushing value, Los Angeles abrasion, and other tests as well.

To evaluate the engineering characteristics of Kohat Limestone aggregates for construction use, the samples were tested with standard ASTM (2004), BS 812 (1990), and AASHTO (2009) procedures. The suitability criteria for these aggregates were determined with regard to the observed data from these subjects. The coarser aggregates are used for road pavements where their quality depends on many factors, such as, for instance, impact

resistance. As pointed out by Dhir et al. (1971), the Aggregate Impact Value (AIV) is one of the most important measures of the strength and durability of the aggregate. Moreover, many researchers acknowledge that the shape and orientation of fractures are very important for settlement and failure ratios (Barksdale et al., 1991; Kandhal and Parker, 1998).

In this context, higher hardness and strength are indicated by a lower Aggregate Impact Value, and a higher value indicates lower durability. The Kohat Limestone aggregates were estimated in this way and registered values between 8.81% and 15.69% with an average of 13.63% (Table 1). As shown, the aggregates honored the standards and proved to be excellent for construction.

4. Results and Discussion

4.1 Petrographic Analysis

The Petrographic studies of each sample were carried out using a polarizing microscope at the Mineralogy laboratory of Khushal Khan Khattak University, Karak. The samples of Eocene Kohat Limestone comprised dominantly of calcite, which is more than 90% of the total rock mass, followed by larger benthic foraminifera and a minor amount of quartz, dolomite, iron oxide, broken bioclasts, and other alteration ingredients. The foraminifera include the lockhartia, nummulites, discocyclina, and ranokothelia and echinoderm spines (Fig. 4a, 4b, 4c). The samples are weakly cemented, matrix-supported, and contain inequivalent calcite grains embedded in fine calcite matrix (Figs. 5a, b). Veins are also present, containing interlocking equigranular, relatively coarse-grained calcite minerals. Additional features observed are stylolites, a few micro-cracks, and calcite veins (Figs. 5c-d and 6a-d). The quartz amount varies from 1 to 2%, dolomite is <2%, and iron oxide up to 1%. No reactive reagents setup was observed, showing that limestone samples were found non-deleterious. They would not entangle in Alkali silica and alkali carbonate reaction if used with ordinary Portland cement, and are

also found to be hydrophobic and can be safely used in asphalt cement concrete.

4.2 Engineering Properties

The mechanical properties of limestone, for its use as building stone, are critical to its suitability for construction applications. Investigation of these properties helps ensure the durability, safety, and cost-effectiveness of limestone in building construction. Like other construction materials, the Kohat limestone in the Sur Dag Karak area will have to fulfil the required engineering criteria for it to be used as dimension stone or building stone, recognized by the International Society of Rock Mechanics (ISRM). Based on the required criteria, the following lab tests were conducted.

4.2.1 Los Angeles Test

The values of this test are used to determine the strength of aggregate to stress endured in conditions. The resistance to disintegration and degradation under physical and chemical conditions determines the toughness of aggregate (Neville and Brooks, 1987; Gondal et al., 2008; Khan, 2000; Uger et al., 2010). The samples under investigation show good results with compressive strength and bonding strength of concrete by following within the purview of standard limits when compared with standardized values for aggregates (AASHTO, T-96). The Los Angeles test results of the Kohat Limestone aggregate vary from 20.6 to 24.7 with an average of 22.816% (Table 1) against the maximum permissible values of 50%, 35% and 40% for sub-base, cement concrete, and base coarse, respectively. These low values of the mentioned test ensure that the aggregate of the Kohat Limestone is within the standard limits that justify its use for road and concrete works as aggregate.

4.2.2 Aggregate Impact Values Test (AIV)

The behavior of the aggregate to sudden load and stress is determined through the AIV test. Generally, aggregates with low strength easily degrade once they

are subjected to a sudden load. The traffic load can cause serious failure of the coarse aggregate used in road pavements. The good quality aggregate can be known because of the Impact value (Ahsan et al., 2009). The shape and fractured orientation also determine the settlement and failure ratio (Barksdale et al., 1991; Khandal and Parker, 1998). The maximum impact value of the present work is 15.63% recorded in EKL-3 (Table 1). The average value of samples from Kohat limestone is 13.63% which is within the standard values of AASHTO, ASTM, and NHA.

4.2.3 Crushing Value Test

To know about the gradual stresses applied on the road by vehicles, which could degrade the aggregate and strength behavior of aggregates, the crushing value is evaluated (AASHTO, 1990). The performance and quality of aggregates have a direct relation with the strength of aggregates, with higher crushing values indicating good quality and lower crushing values indicating poor quality of aggregates (AASHTO, 1990). Road and concrete pavements are the major structures that experience diverse loads. The crushing value of aggregate indicates the packing behavior of grains, its competent nature, and composition within the parent rock (Collis and Fox, 1985). The maximum crushing value for aggregate is 30% which is specified by international agencies and should be used in construction and road work (AASHTO, 2009; ASTM, 2004), and 22.5% (NHA, 1998). The crushing value ranges from 9.4% (EKL-2) to 14.7% (EKL-8) with an average value of 13.272% in the current study (Table 1), which is in concordance with the standards. The results of the current study indicate that the aggregate is of good quality.

4.2.4 Soundness Test (ASTM C-88-90 AASHTO T-104)

This test is used to find out the degradation and disintegration of aggregates caused by weathering conditions (AASHTO, 2009). The aggregate material

must be sufficiently resilient to withstand a variety of surface weathering conditions, including freezing and thawing effects and thermal fluctuations (Khan et al., 1991). Generally, those geological materials that are easily degradable are avoided for their use as aggregates (Gondal et al., 2007; Ahsan, 2009). The maximum permissible standard value of 12% both for the use of aggregate in road and concrete structure and loss by action of sodium sulfate, is set (AASHTO T-104). Aggregate having a value above 12% is of poor quality and is not recommended for use in road and concrete structures. EKL-12 had the highest value in the examined samples, at 1.03%, whereas EKL-3, 6, & 9 had the lowest value, at 0.7%. The average value is 0.88%,

falling in the tolerable limits of standards (Table 1).

4.2.5 Sieve Analysis (AASHTO T- 85)

Sieve analysis is performed manually to check the aggregate size distribution, which helps in the selection of the best aggregate size for any civil structure. The size of the aggregate used in any system significantly impacts the reliability and efficiency of any civil work (Bell, 1993). Aggregate grading in concrete base pavement is the key agent for determining the volume of cement paste and fine aggregate in the concrete mixture (Fuller and Thompson, 1907). It is used according to standards for the classification of soil and aggregate for different layers of ground.

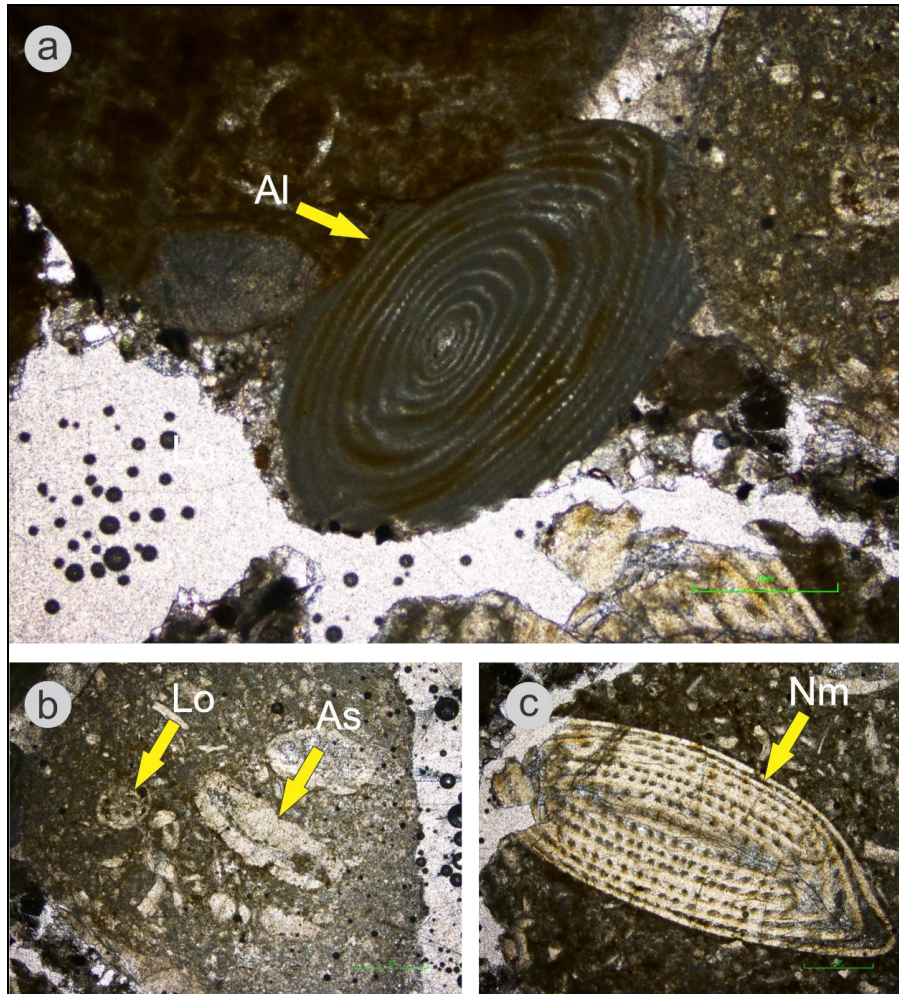


Fig. 4. The composite photomicrograph showing larger Foraminifera content in Kohat Formation of the southeastern Kohat basin (a) Alveolina (Al), (b) Lockhartia (Lo) and Assilina (As), and (c) Nummulites (Nm).

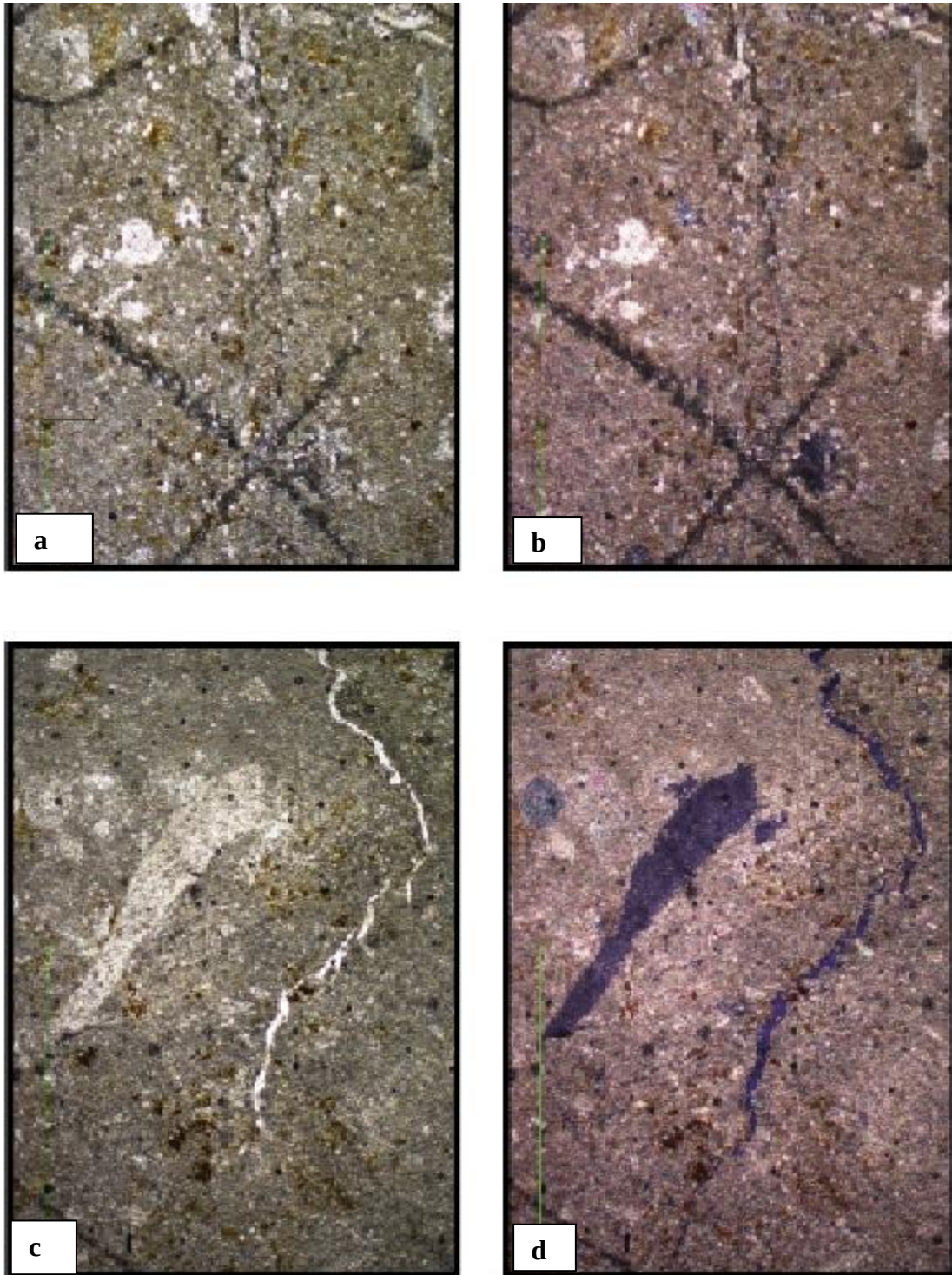


Fig. 5. The composite photomicrographs showing stylolite and inequigranular calcite minerals in the Kohat Formation of the southwestern Kohat basin (a) and (b) show stylolites, and (c) and (d) inequigranular calcite minerals in PPL and XPL, respectively. A 20mm resolution is used. Scale for all the above microphotographs is 1mm.

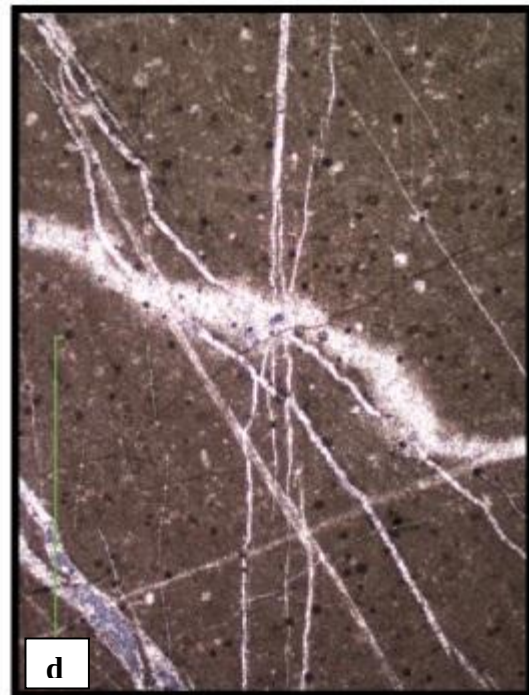
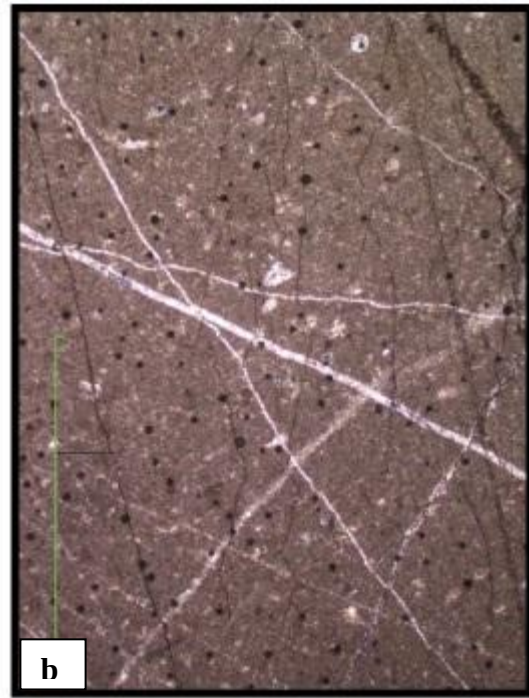


Fig. 6. The composite photomicrographs showing microcracks and calcite *veins* present in the Kohat Limestone of the research area. Figs. (a) and (b) are showing intense microcracks, and (c) and (d) are showing dominant veins in PPL and XPL, respectively. Scale for all the above microphotographs is 1mm.

Table 1: Engineering properties of the Kohat Limestone in the study area.

Sample No.	Specific Gravity	Water Absorption %	Soundness test %	Los Angeles Abrasion	Crushing value %	Elongation value %	Flakiness value %	Impact value %	Area coated 60/70 Grade bitumen	Area coated 80/100
EKL-1	2.598	0.82	0.9	24.7	10.8	8.0	10.6	11.1	Above 95%	Above 95%
EKL-2	2.652	0.57	0.8	23.3	9.4	9.0	9.0	8.81	Above 95%	Above 95%
EKL-3	2.642	0.59	0.7	21.1	13.9	10.0	8.7	15.69	Above 95%	Above 95%
EKL-4	2.654	0.62	1.02	24.2	12.7	9.8	10.8	14.16	Above 95%	Above 95%
EKL-5	2.647	0.70	1.0	24.5	15.0	7.8	9.6	13.97	Above 95%	Above 95%
EKL-6	2.652	0.59	0.7	20.6	14.2	6.9	11.5	14.43	Above 95%	Above 95%
EKL-7	2.652	0.63	0.9	22.9	14.6	9.8	8.9	14.80	Above 95%	Above 95%
EKL-8	2.656	0.64	1.01	23.5	14.7	11.0	10.5	12.70	Above 95%	Above 95%
EKL-9	2.644	0.80	0.7	23.1	13.6	9.0	9.8	14.9	Above 95%	Above 95%
EKL-10	2.653	0.61	1.00	21.4	12.1	8.6	9.3	15.3	Above 95%	Above 95%
EKL-11	2.636	0.65	0.8	22.2	14.6	7.9	9.6	12.9	Above 95%	Above 95%
EKL-12	2.675	0.64	1.03	22.3	13.6	8.8	9.9	14.8	Above 95%	Above 95%
Average %	2.647	0.655	0.88	22.81	13.2	8.690	9.85	13.63	Above 95%	Above 95%
AASHTO Standard	2.5 – 2.9	< 2.0	12	<40	45	----	---	----	---	----
NHA Standard	2.5 – 2.8	< 2.5	12	<40	45	15	25	---	---	---
ASTM Standard	2.5 – 3.0	< 2.0	12	<45	≤45	----	----	---	---	----

4.2.6 Flakiness and Elongation

This test is used to calculate the allotment of flat and elongated particles in the aggregate mix (Hartly, 1974), which causes a serious problem during the infield performance of aggregate base structure and compaction (Britton, 1968; Salih and Sravana, 2013). A good quality aggregate lacks flat and elongated particles, which results in increasing the durability and

workability of the material and road works (Molugaram et al., 2014). The maximum allowed values of Elongation index and Flakiness index are 25 % (BS, 1985-812). The flaky and elongation index in the present study is below 13% which is the maximum allowed range (NHA, 1998). The flaky index varies from 8.3% for EKL-3 to 11.5% for EKL-6, whereas the elongation index is recorded in between 7.8% for EKL-5 to 11.00% for EKL-8 (Table 1). The

average value of flakiness is 9.85% and elongation 8.690% (Table 1), which shows that the shape of Kohat limestone aggregates is not an issue for any constructional use.

4.2.7 Coating and Striping of Bitumen (AASHTO T-182, ASTM D-1664)

To detect coating and adherence capacity among aggregate and bitumen, the coating and stripping of bitumen test is physically performed in laboratory conditions (Gondal et al., 2009; Kazi et al., 1980). This is a surface phenomenon which depends on the geological material properties (Tarrer and Wagh, 1991). To improve the infield performance of asphalt mix roads, the aggregate to bitumen link must be robust enough to withstand striping (Jamieson et al., 1995). The Aggregate bitumen's coating proportion in the current study is more than 95% (NHA, 1998). The highest percentage of 97.1% was recorded in EKL-8 (Table 1).

4.2.8 Specific Gravity and Water Saturation Value of Aggregate (AASHTO-T85)

It is the ratio of sample weight to the volume of water given (AASHTO, 1999). This property of the aggregate is used to measure the strength and efficiency of aggregate (Smith and Collis, 1993). The higher specific gravity value, which is the compositional factor, and the thicker packaging of mineral grains in the geological material (Khandal and Lee, 1997; Ullah et al., 2020; Afrasiab et al., 2024). High specific gravity content increases structural efficiency in the field (AASHTO, 2009). Specific gravity is used as a method to determine the volume of aggregate that is used in concrete mixture, mix-asphalt, and other mixtures for various construction uses.

Specific gravity is an indirect method for measuring the aggregate absorption value (ASTM, 2008). To measure the spaces of voids within the mineral grains of aggregate, the absorption value is used. Absorption is inversely proportional to the aggregate's specific gravity; a high specific gravity will have a low absorption value (Schmidt and Graf,

1972). High-absorption aggregate designates bad quality, and low-strength aggregate is avoided for use in structures experiencing diverse loads (Khan, 2009). High absorption value affects the durability of civil structures for a long time, especially in asphalt mix structure (Collop et al., 2004). In the recent evaluation, the specific gravity value for Kohat limestone aggregate ranges from 2.598 (EKL-1) to 2.675 (EKL-12), with the mean value of 2.647. There are no defined limits for specific gravity, but good quality aggregate is the aggregate with a lower value. The absorption value is derived indirectly from the specific gravity and ranges from 0.57 (EKL-2) to 0.82 (EKL-1), with the mean value of 0.88. The absorption value in a recent study is lower than the maximum permissible value of 2.5.

5. Conclusions

The present study provides a comprehensive evaluation of the geological, petrographic, and engineering characteristics of the Eocene Kohat Limestone exposed in the Sur-Dag section of the Kohat Basin. The Kohat Limestone, predominantly composed of calcite with minor accessory minerals, exhibits significant variations in textural attributes and diagenetic features, indicating its suitability for various industrial applications.

Engineering investigations, including Los Angeles Abrasion, Aggregate Impact Value, and Crushing Value tests, confirm that the Kohat Limestone meets the standard criteria established by AASHTO, ASTM, and NHA for use as a construction aggregate. The results demonstrate that the studied limestone possesses high durability, low water absorption, and adequate resistance to mechanical stress, making it suitable for applications in road pavements and concrete structures. The petrographic analysis further supports its viability by revealing a dense, calcite-rich composition with minimal deleterious materials, ensuring long-term stability in engineering applications.

Despite its favourable physical and mechanical properties, future research should explore additional geochemical assessments and long-term weathering effects to further validate the performance of Kohat Limestone in diverse environmental conditions. Moreover, comparative studies with other regional limestone deposits could enhance the understanding of its relative advantages and potential industrial utility. The findings of this study contribute valuable insights into the engineering potential of the Kohat Limestone, in terms of construction aggregate for civil engineering purposes, in Pakistan.

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Author contributions

Nazir-ur-Rehman: Supervision, formal analysis, investigation, methodology, and writing—original draft. Mumtaz Ali Khan: conceptualization, validation, and writing—review and editing. Afrasiab: data curation, project administration, and writing—review and editing. Ishtiaq Zaman: formal analysis, investigation, and writing—original draft; Khalid Khan: validation and writing—review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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