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Geotechnical and geochemical studies of Eocene limestone of Kohat formation for its use as concrete aggregates

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ABSTRACT: *The Eocene limestone of the Kohat Formation is well exposed in the Kohat, Hangu and Bannu districts. It is cream to gray in color, hard, compact, well-bedded and fossiliferous. The limestone of Kohat Formation has been evaluated mineralogically, chemically and physically, for its use as concrete aggregates during present study.*

Mineralogically, the studied limestone is dominantly calcite with abundant fossil shells. Fine-grained quartz, chalcedony, clay, dolomite and opaque phases are present in minor amount. The limestone generally has fine to medium-grained granular mosaic with microfossils. Deleterious minerals for concrete are generally found in the argillaceous variety of the studied limestone. Chemically, the studied limestone (by weigh) is classified as high-calcium limestone, with $CaCO_3$ between 81.23 and 98.93%. The average chemical compositions of various cements manufactured in N.W.F.P. are within the ASTM limits. The alkali-silica reactivity graph of the limestone's aggregates also confirms the petrographic observations. Physical properties (i.e., soundness, water absorption, Los Angeles abrasion and specific gravity) are generally in accordance with the ASTM standards for aggregates to be used in concrete.

The studied limestone of the Kohat Formation except its argillaceous variety, found in the eastern part of the study area, is generally free of dolomitization and has no other deleterious substances as far as the durability of concrete is concerned. This Eocene limestone of the Kohat Formation is, therefore, recommended for its use as concrete aggregates.

INTRODUCTION

Pakistan has tremendous resources of limestone, which can be utilized for construction purposes. There are extensive limestone belts exposed in the entire foreland and thrust belts including Kohat (Kohat Basin), Nowshera (Attock-Charat Range), Hassanabdal (Lesser Himalayan Range), Wah (Margalla Hills), Beth Kas-Khairabad-Daudkhel (Salt Range), Pezu (Marwat Range), Moghal Kot and Zinda Pir (Sulaiman Range), Rohri-Hyderabad-Thatta (Indus platform), Jangshahi-Murli Hill-Mango Pir (southern Kirthar Range) and many other localities in Baluchistan and northern Pakistan (Gilgit-Baltistan) (Shah, 1977).

The study area is situated in the Kohat district of north west-Frontier Province (Figs. 1 & 2). It is a part of the northern Kohat basin, which is composed of four formations of Chharat Group namely Panoba Shale, Sheikhan Formation, Kuldana Formation and Kohat Formation (Meissner et al., 1968; 1974; Shah, 1977). The Eocene limestone of the Kohat Formation consists of the Habib Rahi Member (upper member) and the

Kaladhand Member (lower member). The Kohat Formation forms 30% of Eocene limestone in the area (Gauhar, 1966). It is creamy to light gray, hard, compact, thinly bedded, fine-to-medium-grained with abundant fossils of Assilina and Nummulites (Meissner et al., 1968; 1974; Shah, 1977). The Kohat Formation is widely exposed in the Kohat Province of the upper Indus Basin (Meissner et al., 1968 & 1974). It is exposed in the Kohat, northern Bannu and eastern Hangu districts and is a dominant rock unit in the study area.

According to Lea (1976) and Boynton (1980), the use of limestone as concrete aggregate has sometimes been suspected on account of the unsuitability of the porous grade rocks and also because of the widespread fallacy that limestone concrete is less resistant to the action of fire relative to the concrete made from other aggregates. But recent workers (e.g., Mehta, 1986; Hobb, 1988) suggest that the limestone has an excellent thermal resistant because the surface concrete, containing limestone's aggregates, provides a good shield against fire after calcining.

The limestone of the Kohat Formation with over 1.5 million tons surface exposure (Gauhar, 1966) can be used as a concrete aggregate. But before its use as concrete aggregates, it should be evaluated by using different international standards such as American Society for Testing and Materials (ASTM). Presently the limestone of the Kohat-Formation is used as raw material for cement manufacturing by the Kohat Cement factory. However, no proper scientific work has been carried out on the studied limestone regarding its evaluation for its use as concrete aggregates. The present study is a part of the studies conducted by Goher, 1999 and Shah and Goher (2000) deals with the evaluation of mineralogical, geochemical properties and inherent reactivity along with the physical properties (i.e., soundness, water absorption, Los Angeles abrasion and specific gravity) for the limestone coarse aggregates of the Kohat Formation, exposed in Kohat district. These studies were carried out in conjunction with the chemistry of local ordinary Portland cements in order to figure out its use as concrete aggregate.

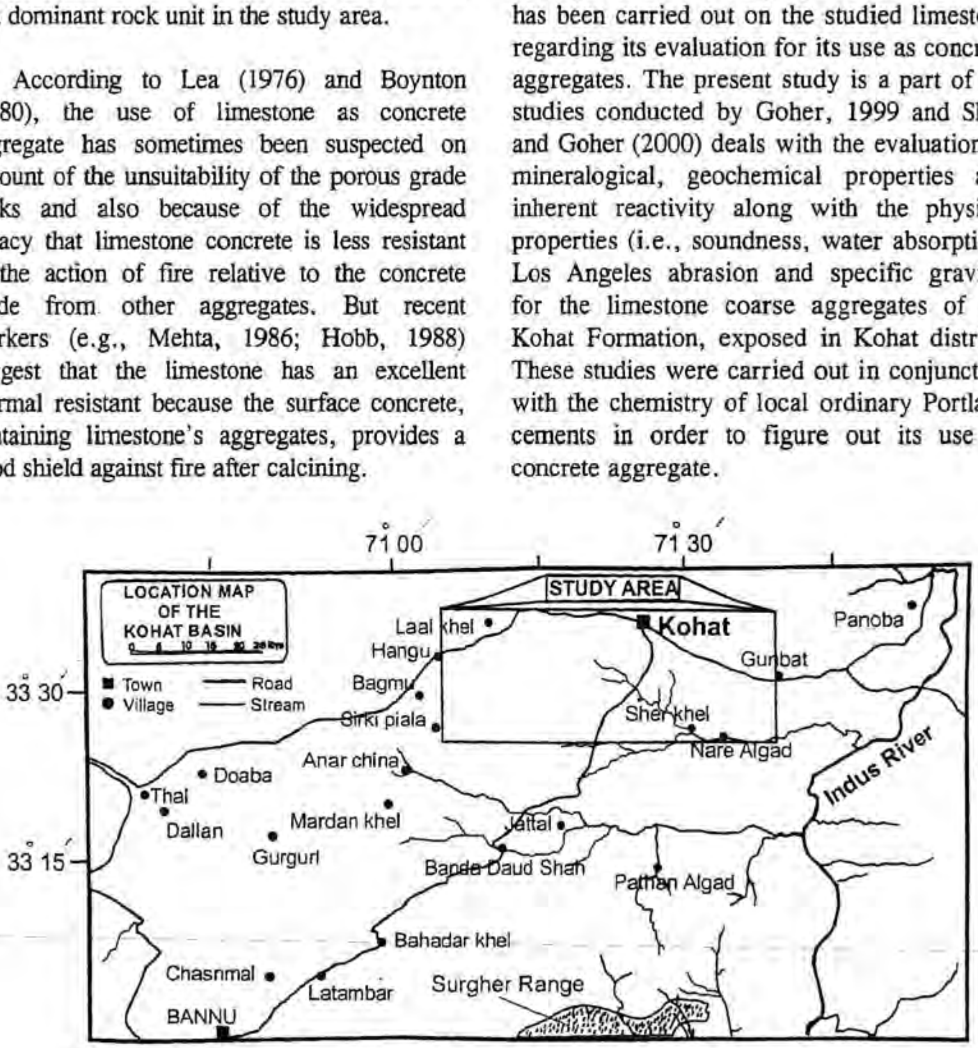

Fig. 1. Location of the study area within the Kohat Basin, Pakistan.

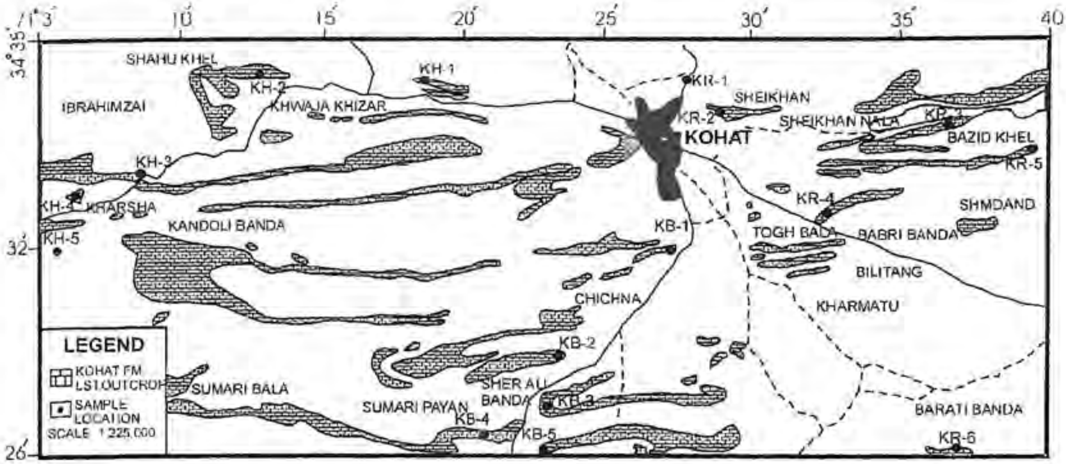

Fig. 2. Geological map of the Kohat and surrounding area, showing the out crops and sample locations of the limestone of the Kohat Formation (simplified after Meissner et al., 1974).

PETROGRAPHY

In thin sections, the limestone of the Kohat Formation is dominantly composed of calcite and fossil shells, with lesser amount of dolomite, quartz, clay and opaque phases. The rock has fine-to medium-grained, granular mosaic with microfossils.

Calcite (80 to 90%) is generally fine-grained but patches of medium-to coarse-grained anhedral calcite are also common. This calcite seems to be authigenic (primary) in origin and has been precipitated in situ. The medium-to coarse-grained calcite grains are generally interlocked. Micro-fractures filled with fine-to medium-grained calcite micro-veins are also common in these rocks, which are considered as diagenetic (secondary).

Various types of microfossils such as foraminifers recognized as Assilina and Nummulites are very common in these rocks and some time constitutes more than 60% of the whole rock. These fossils are set in a fine-grained calcite mass, which also act as a cementing material. The tests or shells of the fossils are dominantly calcitic. The interior of these tests is replaced by the crystalline calcite. In most cases, the original foraminiferal tests are replaced by calcite and the filling is left in the form of interior mold or cast. These are, therefore, appear as pseudofossils. These fossils are generally bioturbated and are generally filled in by the secondary calcite. Dolomite in traces is intimately associated with calcite in the micro-veins and is, therefore, considered as secondary phase.

Quartz is generally found in trace amount, however, one sample, collected from Bazid Khel, has about 10% quartz. This quartz occurs in the form of subhedral medium-grained, detrital material. Chalcedony in certain cases has been noticed in the form of spherulite in the fossil's test. Clay and siderite in trace amount are present as fine-grained disseminated material in many thin sections.

GEOCHEMISTRY

Chemistry of Limestone

The major element chemistry of the limestone of the Kohat Formation is given in Table 1. It is evident from this table that, the SiO_2 is in the range of <0.50 to 13.90 wt%, Al_2O_3 is less than 0.74 wt%, Fe_2O_3 is less than 0.30 wt%, MnO is negligible; MgO is up to 2.69 wt% and CaO is ranging from 46.07 to 57.03 wt%. Among alkalies, Na_2O is less than 0.50 wt% while the K_2O is negligible. The loss on ignition is more or less constant (~ 43 wt%) with the exception of one sample which has 35 wt% of loss on ignition (Table1).

The studied limestone generally has very low concentration (<0.50 wt%) of SiO_2. However, three samples collected from Kohat township, Sheikhan Nala and Khawaja Khizar area respectively, are having up to 3.50 wt% SiO_2 (Table 1). One sample collected from Bazid Khel having the highest silica (13.50 wt%) and can be classified as argillaceous limestone.

Alumina (Al_2O_3) is the second largest impurity in the limestone. Both the alumina and silica concentration in the limestone originate from the shelly matters (Pettijohn, 1976). The Al_2O_3 content of the studied limestone is more or less constant. However, two samples collected from Kohat township and Bazid Khel are having little higher Al_2O_3 (Table 1).

Iron in the form of oxides and sulfides occurs as another impurity in the limestone which if present in higher amount can cause deterioration in the building construction (Boynton, 1980). Fe_2O_3 contents of the studied limestone are negligible at Mitha Khan, Ibrahimzai post and Bahadur Banda (Table 1). Few other localities such as Kohat township, Sheikhan village, Sheikhan Nala, Bazid Khel, and Baratai Banda have relatively high Fe_2O_3 contents (Table 1). The rest of the samples have less than 0.20 wt% Fe_2O_3 (Table 1).

Manganese oxide (MnO) in the studied limestone is generally found in traces (Boynton, 1980). There negligible amount of MnO in almost all the samples except one sample at Bazid Khel, which has relatively high content (0.25 wt%) of MnO (Table 1).

Magnesium oxide (MgO) in the limestone is a function of both the magnesium content of skeletal debris and also the other dolomitization process due to post-depositional events (Pettijohn, 1976). The increase of MgO in limestone, therefore, increases the dolomitic component of limestone and may aggravate the alkali-carbonate reaction. The studied limestone specimens are having very low amount of MgO (<2.69 wt%) and are, therefore, considered pure limestone. Majority of the aggregate samples have low (<1.0 wt%) MgO (Table 1). The sample taken at Badadur Banda, however, is having relatively high (2.69 wt%) MgO (Table 1).

Calcium oxide (CaO) and CO_2 are the highest constituent of limestone. The studied limestone of the Kohat Formation has high (52 wt%) and more or less constant amount of CaO in almost all the samples, except one sample taken at Bazid Khel which has the lowest content (46.07 wt%) of CaO (Table 1). Sodium oxide (Na_2O) and potassium oxide (K_2O) are considered as traces with respect to the pure stone chemistry (Boynton, 1980). Both these oxides are very low (< 0.50 wt%) in total (Table 1).

Due to high concentration of calcite ($CaCO_3$), the loss on ignition is high (>42 wt%) and more ore less similar in almost all the samples. One sample taken from Bazid Khel have relatively low content of loss on ignition (L.O.I.) and is consistent with the low concentration of $CaCO_3$ content (Table 1). This is in agreement with the petrographic observation that almost all the studied aggregates of the Kohat Formation are pure high-calcium limestone having calculated calcium carbonate more than 95% except one sample from Bazid Khel which has about 81% $CaCO_3$ (Table 1).

TABLE 1. CHEMICAL COMPOSITION OF LIMESTONE OF THE KOHAT FORMATION AT DIFFERENT LOCALITIES (FOR SAMPLE LOCATION SEE FIG. 2)

	KR-1	KR-2/a	KR-2/b	KR-3/a	KR-3/b	KR-4	KR-5	KR-6	KB-1	KB-2	KB-3	KB-4	KB-5	KH-1	KH-2	KH-3/a	KH-3/b	KH-4	KH-5
SiO_2	1.30	0.60	<0.50	3.50	<0.50	<.50	13.9	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	1.50	<0.50	<0.50	<0.50	<0.50
Al_2O_3	0.67	0.52	0.53	0.52	0.53	0.47	0.74	0.57	0.51	0.62	0.47	0.53	0.58	0.49	0.47	0.46	0.51	0.58	0.51
Fe_2O_3	0.27	0.19	0.24	0.30	0.16	0.13	0.25	0.25	0.19	0.10	0.1	0.15	0.12	0.05	0.15	0.08	0.22	0.15	0.06
MaO	0.00	0.00	0.00	0.01	.0.01	0.02	0.25	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.02	0.01
MgO	0.93	1.24	0.62	0.73.	1.04	0.93	0.62	0.62	0.21	0.31	0.83	0.00	0.00	0.00	1.24	0.62	1.14	1.97	2.69
CaO	52.61	55.54	56.8	52.79	54.91	53.69	46.07	52.43	57.03	54.76	55.12	53.6	53.6	55.52	52.2	53.51	53.74	54.59	56.11
Na_2O	0.37	0.47	0.46	0.43	0.48	0.43	0.45	0.35	0.4	0.44	0.41	0.42	0.42	0.43	0.36	0.39	0.43	0.36	0.39
K_2O	0.04	0.04	0.03	0.04	0.03	0.01	0.02	0.05	0.03	0.02	0.02	0.43	0.02	0.02	0.03	0.02	0.02	0.03	0.02
L.O.1.	41.88	42.33	42.78	42.36	42.97	42.81	35.74	42.36	43.21	43.21	43.21	0.02	43.17	42.88	43.21	43.53	43.35	43.41	12.67
Total	98.07	100.93	101.96	100.68	100.6	98.99	98.04	97.14	102.03	99.97	100.57	42.88	98.41	99.9	99.17	99.12	99.93	101.61	102.9
$CaCO_3$	95.18	96.20	97.23	96.27	97.66	97.30	81.23	96.27	98.07	98.20	98.00	99.9	98.11	97.45	98.20	98.93	98.52	98.66	96.98
S_c	21.66	9.99	7.50	58.31	7.50	7.50	231.57	7.50	7.5	7.50	7.50	97.9	7.50	7.50	24.99	7.50	7.50	7.50	7.50
R_c	60.00	36.50	22.50	47.50	16.50	9.00	10.00	22.50	32.5	7.50	17.50	97.45	27.50	21.50	62.50	25.00	27.50	10.00	8.50
$35+1/2R_c$	65.00	53.25	46.25	58.75	43.25	39.50	40.00	46.25	51.25	38.75	43.75	7.5	48.75	45.75	66.25	47.50	48.75	4.00	39.25

Chemistry of the N.W.F.P. Cements

The chemistry of ordinary Portland Cement (OPC) largely depends upon the geochemistry of its raw materials that is limestone, argillaceous rocks (e.g., clay, shale and slate etc.), gypsum and silica sand (Lea, 1976). In order to study the chemistry of Portland cement used in concrete, cement samples have been collected from three cement factories (i.e., Cherat Cement Company, Kohat Cement Company and Lucky Cement Company) for chemical analyses. The major oxides data of these cements have been presented in Table 2. It is clear from this table that chemically the Kohat cement is comparable with both Lucky and Cherat cement.

The averages of the major oxides, tricalcium aluminate and equivalent alkalies for the ordinary Portland cement of these three companies are diagrammatically compared with the maximum limits specified by ASTM in Figure 3. Silica (SiO_2) in cement may comprise up to 25% of total constituents (Lea, 1976). The average SiO_2 contents in the studied cement are within the limits of ASTM. The Lucky Cement, however, has relatively high SiO_2 (Fig. 3).

Although the alumina (Al_2O_3) and ferric oxide (Fe_2O_3) by no mean are equivalent to each other but their effects are closely interconnected (Lea, 1976). Their excess may form rings in the kiln and abnormal variation in their proportion hastens the cement's setting time. Thus the main role of alumina and ferric oxide in the OPC is to reduce the clinking temperature and production of high early strength. The Al_2O_3 content in the studied cement specimens of Kohat and Cherat brands are slightly higher whereas in Lucky cement, it is within the ASTM standards (Fig. 3). The concentration of Fe_2O_3 in all the three varieties is similar and is within the specified limits of ASTM (Fig. 3). The concentration of manganese oxide (MnO) is usually less than 0.1% in cement made from normal raw material (Lea, 1976). The MnO content of all the three varieties of cement is almost negligible and similar (Table 2)..

TABLE 2. CHEMICAL COMPOSITION OF THE N.W.F.P. ORDINARY PORTLAND CEMENT

	ASTM	Lucky Cement Co.				Kohat Cement Co.				Cherat Cement Co.			
	max limit C 150-94	I	II	III	Avr.	I	II	II	Avr.	I	II	III	Avr.
SiO_2	20.00%	21.00	21.70	19.1	20.6	19.50	17.80	16.60	18.0	19.50	18.20	18.50	18.70
Al_2O_3	6.00%	4.36	4.21	5.89	4.82	6.75	7.48	7.89	7.37	7.73	7.81	7.58	7.71
Fe_2O_3	6.50%	2.79	2.73	2.73	2.75	2.41	2.32	2.66	2.46	2.75	2.75	2.66	2.72
MnO	5.00%	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.05
MgO	6.00%	2.38	1.92	2.01	2.1	1.65	1.66	1.47	1.59	1.77	1.05	0.99	1.27
CaO	--------	65.87	66.45	65.66	65.99	65.75	64.92	65.04	65.24	65.5	65.67	65.84	65.35
Na_2O_8	--------	0.52	0.56	0.52	0.53	0.29	0.28	0.29	0.29	0.44	0.47	0.47	0.46
K_2O	--------	0.8	0.71	0.68	0.73	0.75	0.69	0.44	0.63	0.66	0.71	0.71	0.69
Loss on ignition	3.00%	0.97	1.22	0.77	0.99	0.69	0.22	0.9	0.6	0.8	0.91	0.97	0.89
Total	--------	98.74	99.55	97.41	98.56	97.84	95.42	95.34	96.2	98.2	97.62	97.77	97.84
C A	15.00%	6.83	6.54	10.99	8.12	13.81	15.9	16.41	15.37	15.8	16.04	15.59	15.82
Equivalent alkalies	0.60%	1.05	1.03	0.97	1.02	0.78	0.73	0.58	0.7	0.87	0.94	0.94	0.92

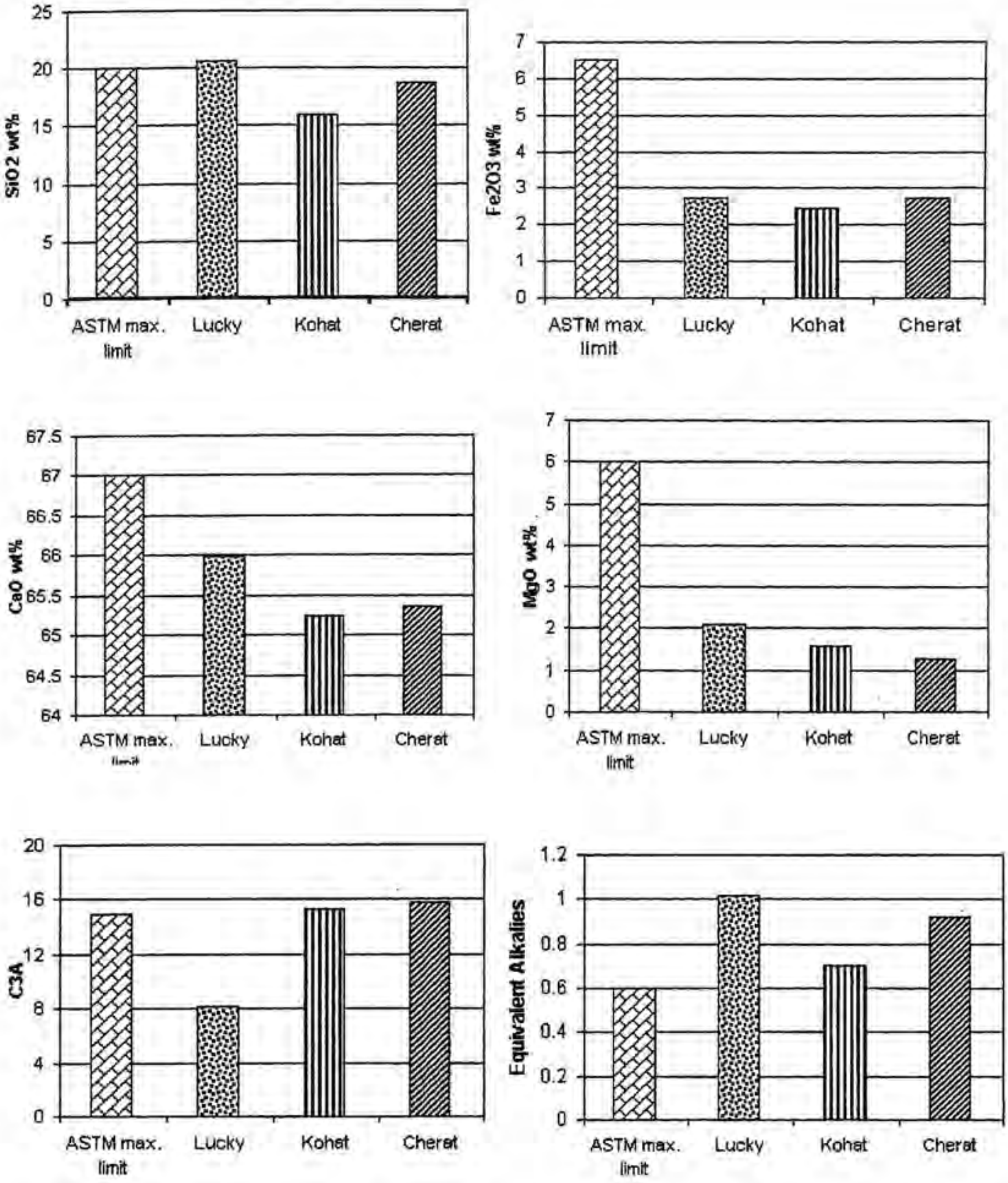

Fig. 3. Comparison of the chemistry of the ordinary portland cements of the N.W.F.P. with those of the ASTM.

Magnesia (MgO) usually act as flux during cement manufacturing thus, facilitating combustion and rendering of clinker (Lea, 1976). But its abnormal concentration led to long term unsoundness. The average MgO contents of Lucky cement are relatively high but are still within the maximum limits specified by ASTM (Fig. 3).

Approximately 75% of Portland cement raw material consists of lime (CaO) bearing material. Due to better cementing property of hydraulic lime, it is widely used in cement manufacturing. The concentrating of many cement compounds (tricalcium silicate, dicalcium silicate etc.) largely depends upon the lime contents (Lea, 1976). The average CaO content in all the three studied varieties of cements are more or less similar (Table 2).

The tricalcium aluminate (C_3A) controls the setting time of the ordinary Portland cement (Gilkey, 1952; Lea, 1976). Its concentration in the cement largely depends upon alumina and ferric oxide contents. The average C_3A contents in the studied cements are within specified limits (Fig. 3).

Potash and soda contents are usually present in minute quantity in ordinary Portland cement clinker which are readily soluble in water resulting increase in the pH for the concrete pore solution (Lea, 1976; Hobb, 1988). This increase in pH of pore solution may aggravate the alkali-aggregate reaction thus damaging the concrete structures. The equivalent alkalis in the studied cements are relatively higher as compared to the permissible limits of ASTM (Fig. 3). Therefore, expansion tests (ASTM C 227-90, C 342-90 and 1260-94) need to be conducted to ensure possible reactivity caused by cement's alkalis in the mortar.

Alkali-silica reactivity of limestone aggregates

The alkali silica reactively (ASR) has been determined by the chemical test (C289-94) of ASTM (1994). The basic theme of this test is that the reactive material will release more molar equivalent of silica into solution for a given reduction in alkalinity and that this greater proportion of silica will form swelling gel in the concrete. Therefore, reaction between sodium hydroxide solution and siliceous aggregate is correlated with the performance of aggregate in concrete structure (Lea, 1976). Thus the quantity of dissolved silica (Sc) and reduction in alkalinity (Rc) determined in millimoles per liter is plotted against each other in Figure 4. This graphical presentation between dissolved silica and reduction in alkalinity for the limestone of Kohat Formation suggest that only argillaceious limestone collected from Sheikhan Nala and Bazid Khel) stands potentially deleterious whereas all the other samples of the studied limestone are found innocuous for concrete (Fig. 4) This can further be testified by the method (C33-93) of ASTM (1994) according to which those aggregates will be considered potentially deleterious if $Sc > (35+1/2Rc)$ and $Rc < 70$.

It is evident from Table 1 that the sample No.KR-3/a and KR-5 have higher Sc as compared to the relation $35+1/2Rc$ and are, therefore, considered deleterious. The ASR test, therefore, suggest that the argillaceous limestone at Sheikhan Nala and Bazid Khel areas is not feasible for its use as concrete aggregates while rest of the limestone of the Kohat Formation is suitable for its use as concrete aggregates.

PHYSICAL PROPERTIES

Aggregates constitute about 60-80% of the concrete by volume. Their characteristics, therefore, influence the workability, strength and durability of the concrete (Smith, 1979; Boynton, 1980; Derucher & Heins, 1981). Limestone generally yields good quality concrete aggregates under normal conditions (Lea, 1976; Tayler, 1977; Metha, 1986; Hobb, 1988). The Eocene limestone of Kohat Formation has, therefore, been grouped based upon their geochemical composition and these groups have been evaluated for their physical properties (i.e., soundness, water absorption, Los Angelles abrasion and specific gravity). The results are presented in Table 3. It is clear from this Table that the soundness and Los Angeless abrasion values are within the maximum permissible Limit of ASTM (Table 3). Majority of the studied aggregates have low (< 0.7%) water absorption and the specific gravity is ranging from 2.60-2.70 and is, therefore, suggesting their calcic nature (Boyonton, 1980). All these physical tests suggest that the studied limestone of the Kohat Formation has sufficient resistance to freezing, thawing and shrinking effects.

DISCUSSION

The chemical composition of limestone reflects its mineral composition. As high-calcium limestone is primarily calcite, therefore, the content of both CaO and CO_2 are extremely high (Pettijohn, 1976). Among other constituents that commonly become important is MgO that is derived either by the magnesium content of skeletal debris or due to post-depositional additions. The important minor constituents (impurities) in limestone are silica and alumina, which forms 85-95% of total impurities (Boynton, 1980). These are followed by iron, phosphorus and sulfur but other impurities are so minute that they may be considered as trace elements relative to pure stone chemistry. These included manganese, copper, titanium, sodium, potassium (as oxides), fluorince, arsenic, strontium and others.

TABLE 3. PHYSICAL PROPERTIES OF COARSE AGGREGATES OF LIMESTONE OF THE KOHAT FORMATION

Group No.	PHYSICAL PROPERTIES			
Test title	Soundness (%)	Water absorption (%)	Los Angeles Abrasion (%)	Specific gravity
ASTM method No.	C 88-90	C 127-88	C 131-89	(C 33-93)
ASTM max. limit	12		50.0	
A.	3	0.6	21.2	2.68
B.	1	0.3	20.4	2.70
C.	1	0.4	20.7	2.60
D.	0	0.7	20.8	2.69
E.	0	1.2	21.3	2.72
F.	1	0.7	18.2	2.67

Group A comprises of geochemical sample Nos.KH-2, KR-1, KR-3/a, KR-3/b & KR-6.
Group B comprises of geochemical sample Nos.KR-2/a, KR-2/b & KR-4
Group C comprises of geochemical sample Nos.KB-1, KB-3, & KH-1
Group D comprises of geochemical sample Nos.KB-2, KB-4/a & KB-4/b.
Group E comprises of geochemical sample Nos.KH-3/a, KH-3/b, KH-4 & KH-5.
Group F comprises of geochemical sample Nos.KR-5.

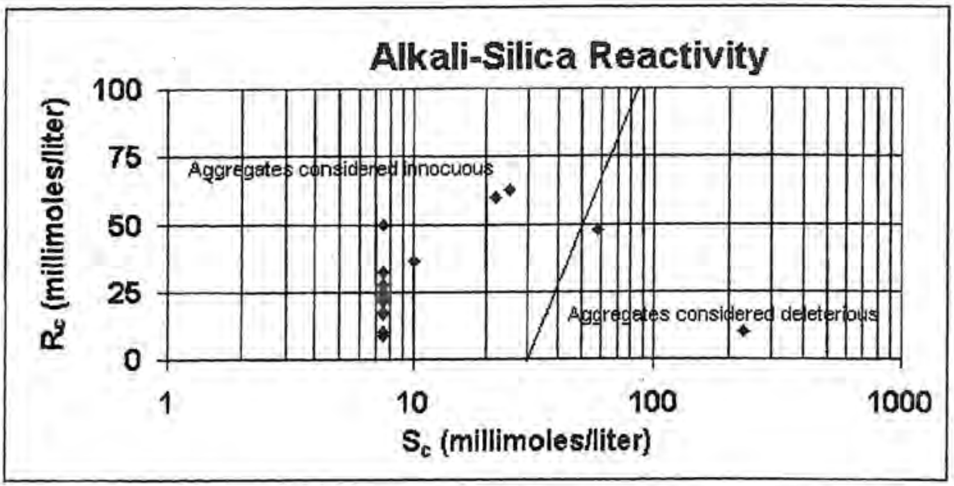

Fig. 4. Distinction between innocuous and deleterious aggregates of limestone of Kohat Formation on the basis of reduction in alkalinity.

The source of these impurities is the non-carbonate detritus minerals incorporated during the formation of limestone (Pettijohn, 1976). Chemically, the studied limestone of Kohat Formation is considered as high-calcium limestone with the exception of few species found in eastern region of the study area where argillaceous matter (especially silica content) increases.

The chemical properties of aggregates are of greater importance because the aggregates contain those constituents which can undergo chemical change or react with the cement in such a way as to cause deterioration or is interface with its setting and hardening. Ferric/iron compounds in aggregates are not considered as deleterious because they react with lime in aggregates without any deleterious effect. However, the oxidation of iron such as oxidation of pyrite, marcasite and pyrrhotite are reported to cause popping out or expansion and deterioration of concrete. Very low Fe_2O_3 content (< 0.30 wt%) and invisible pyrite or any other iron-bearing sulfide in the studied aggregates suggest no deleterious effect due to oxidation in the studied aggregates.

The reacting of the active silica with lime improves the strength, however, its reaction with alkalies causing intensive deterioration (ACI Committee, 1984; Building research Establishment, 1982). These reactions occur when there is high content of alkali in the cement and the presence of higher amount of free silica or other reactive constituents in the aggregates. However, this reaction does not occur when the aggregates of sufficiently low silica or reactive constituents are used with the cement having high (>1.0 wt%) alkali contents. Considering the very low silica content (<1.5 wt%), except two samples (KR-3/a and KR-5) and the absence or negligible amount of other reactive constituents in the studied aggregates, it is suggested that although the various types of cement have more than 0.60% of total alkalis (Table 2), but still the use of these aggregates may not cause any alkali-aggregate reaction in the concrete. The plotting of majority of these aggregates in the field of innocuous aggregates in dissolved silica (Sc) verses reduction in alkalinity (Rc) diagram (Fig. 3) is in consistence with above discussion. The chemical composition of the aggregates (Table 1) further suggest that there are greater chances of formation of insoluble calcium-silicate or calcium-alkali-silicate gel instead of soluble alkali-silica gel which favor the use of these aggregates in concrete.

Alkali-carbonate reaction is another expansion type of reaction in limestone aggregate's concrete under most conditions. This reaction generally occurs between the alkalis of the cement and the aggregates of dolomitic limestone and dolomite. This reaction causes extensive expansion and swelling in the rock, which has deterioration effect in the building construction. It is clear from the petrography and the geochemistry of the studied aggregates that the aggregates are of pure limestone and no dolomitization has been noticed in these aggregates. This is suggestive of no possibility of alkali-carbonate reaction in the concrete of these aggregates.

Petrographic analysis plays an important role in identification of deleterious substances in the aggregates. The petrography of coarse aggregates also identifies the extent of the weathering and alteration of the aggregates. This kind of study on aggregates in building construction is used to determine quantitatively the abundance of potentially alkali-aggregate reactive constituents. According to ASTM (C 295-90) the aggregate constituents capable of alkali-silica reaction in the concrete are; opal, chalcedony, cristobalite, tridymite, siliceous volcanic glass, chert, glassy to crystalline acid volcanic rocks, some argillites, phyllite, metagraywacke, schist, granite gneiss, quartz veins, quartz and sandstone. Among the most important potentially alkali-carbonate reactive rocks are the calcareous dolomite or dolomitic limestone with clayey insoluble residues. There are certain chemically unstable minerals such as soluble sulfates, unstable sulfides which may form sulfuric acid or create distress in concrete whenever are exposed to high temperature and also volumetric unstable minerals such as smectite, montmorillonite and other clay minerals which cause swelling, cracking and expansion in the concrete (Hobb, 1988).

It is clear from the petrography of the studied limestone aggregates that there are no deleterious constituents, which can cause alkali-silica, alkali-carbonate or any physical distortion in the concrete structure. The occurrence of high amount of medium-grained quartz in the aggregates collected at Bazid Khel may cause alkali-silica reaction.

The physical properties of the aggregates are relevant to the behavior of aggregate in concrete and to the properties of concrete made with the given aggregates (Naville & Brooks, 1987). The various physical properties such as, soundness, water absorption, Los Angeles abrasion and specific gravity have been determined for the limestone of Kohat Formation. The composite aggregates of the Kohat Formation are having physical properties within the specified limits of ASTM (C 33-93) and can, therefore, be used in building construction.

It is, therefore, concluded from this discussion that the limestone of the Kohat Formation has no mineralogical, chemical or physical reasons that could render the use of this limestone in the concrete construction. Argillaceous limestone variety present in the eastern part of the study area especially at Sheikhan Nala and Bazid Khel, however, cannot be recommended for use in concrete at this stage without further detail investigation.

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