volume for the same tonnage. The RCA mixes will require approximately 0.5 to 1.0 percent more AC to have equal air voids and voids filled criteria.

Based on the laboratory findings, two controlled test strip pavements were constructed. A testing program was developed so that the quality of the mix could be monitored and compared with other standard paving materials. Test results from the two controlled strips indicate that the RCA mixes are performing better than the standard paving mixes, and that if properly designed and constructed, RCA-asphalt mixes are capable of providing a strong, economical, stable pavement that will yield low deflections.

Pavements constructed in Texas as long as 14 years ago confirm that the RCA-asphalt mixes can yield excellent long-term performance. TSDHPT has enough confidence in RCA-asphalt mixes to have let a contract to pave an Interstate highway with an RCA-asphalt mix.

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Study of Aggregates Used for Concrete in Kuwait

OBADA A. KAYYALI

ABSTRACT

The research reported in this paper was necessitated by (a) the great volume of local and international building contracts in the Middle East and (b) the search for the reasons behind the phenomenon of extensive concrete deterioration. Petrological classification, and chemical and x-ray analyses were performed on the aggregates used for concrete production in Kuwait. The results indicated that the coarse aggregates contain no deleterious materials and have no potentially adverse reactions. Thus the aggregates are suitable for good concrete production. Fine aggregates in their unwashed condition are contaminated with clay and contain too much fines, which necessitates careful washing before being used. High-quality concrete made with these aggregates should be expected if efficient washing of the sand is made and if proper mix design and workmanship are provided.

Concrete in the Middle East has been the subject of several recent publications (1-4). The Middle East, however, is a large area that is vaguely defined. Most of the papers that have the words Middle East in their titles tend to generalize certain conditions that may be true only in a limited part of the area. Evans (5) summarized some important information related to the geology and soil conditions of the countries in the Arabian penninsula: Iran, Iraq, and Egypt. His report implied the distinct differences in concrete products in each of these various countries because of several different factors related to materials, geology, climate, and other variations. Thus, in spite of the temptation for arriving at general rules, it should be borne in mind that local conditions in each state can be of major significance. It is believed that determination of the properties of the constituents of concrete in each region is essential for understanding the factors that influence its behavior in the fresh and hardened conditions.

In this paper identification and properties of the aggregates used in the concrete industry in Kuwait are reported. The reported results are part of continuing research aimed at obtaining a basic understanding of the causes of concrete deterioration in this part of the Middle East.

GENERAL DESCRIPTION

The state of Kuwait is situated in the northeast corner of the Arabian peninsula. It is bordered by Iraq to the north and west, by Saudi Arabia to the south, and by the Gulf of Arabia to the east (Figure 1). Kuwait covers about 15,900 km^2 and has a popu-

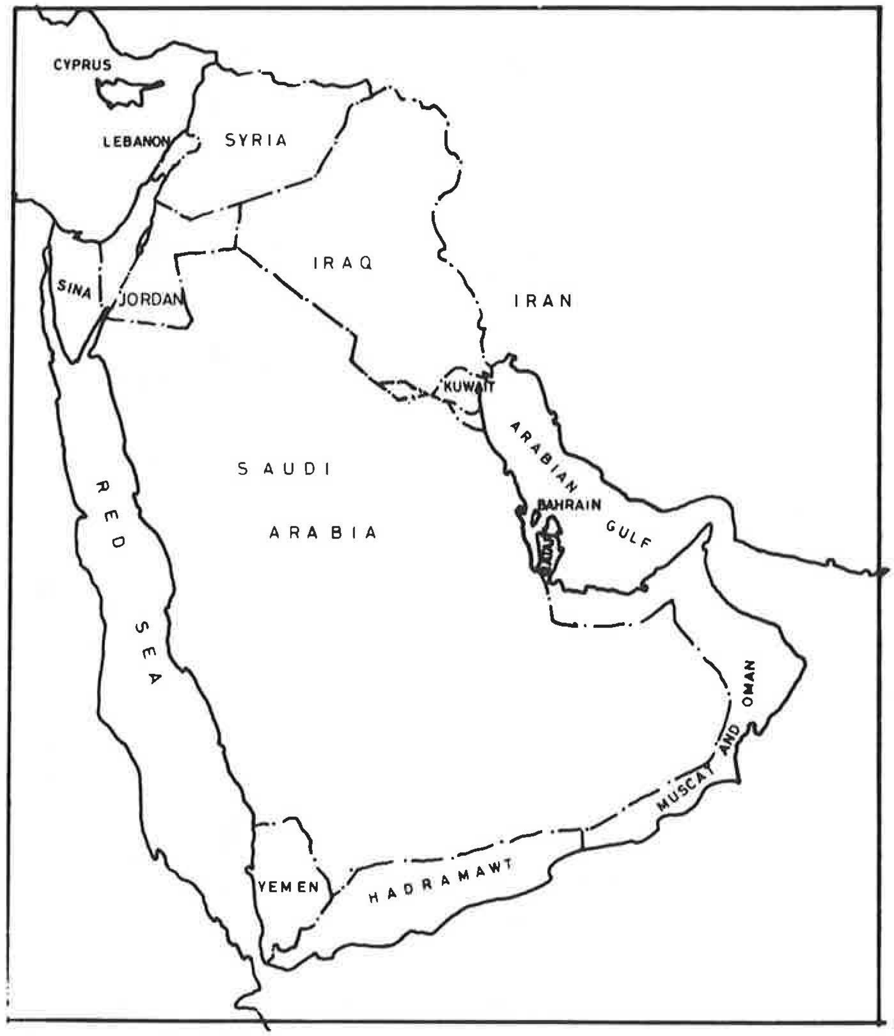

FIGURE 1 Geographic position of Kuwait.

lation of 1.5 million people. The main source of national income is petroleum production, which puts it in the forefront of countries as far as per capita income and standard of living. It is a country of extremely hot weather, where the temperature in the shade during the summer months can exceed 50°C, and the mean maximum in-shade temperature from June to October is about 42°C (6). The surface of Kuwait is formed by sedimentary rocks belonging to the Cenozoic era, ranging from Middle Ecocene to Recent (7,8).

Materials suitable for different construction purposes can be exploited from different parts of the country. Limestone is occasionally found at shallow depths in central and southern Kuwait (9). Exploitable limestone is found to the south of Ahmadi and is currently being used for marine structures and for the manufacture of mineral filler for asphaltic concrete (8). Potentially exploitable sandstone, which could be used for building blocks and low strength concrete, is also found in central areas (8). However, in this paper attention is focused on materials that can be used to produce good quality concrete. These materials are found in exploitable quantities in the northwestern and central regions. Among the formations shown in Figure 2, the materials considered suitable for good concrete production are the gravel-capped ridges and their surroundings and the medium to coarse grey sand. These formations belong to the Pleistocene epoch (9). Materials of lower quality are found in the Dibdibba Formation, which contains medium to coarse, occasionally cemented gravel and sand with calcareous and gypsiferous structure. Fuchs et al. (7) reported that large reserves of loose gravels suitable for concrete use are present in vast areas in northern, central, and western Kuwait. Excavations indicate that loose gravels in sandy matrix occur only on or near the surface.

A comprehensive survey (8) was prepared in 1974 for the purpose of controlling and organizing the natural resources, and it was conducted for most areas of potential and operational gravel pits. It could be concluded from that survey that there existed more than 10 million cubic meters of exploitable gravel that is suitable for good concrete work. The amount of good quality sand suitable for this purpose is estimated around 13 million cubic meters. Based on the previously mentioned studies, the Ministry of Commerce and Industry gave permission for quarries to operate in some parts of the areas of dense gravel and sand (Figure 3).

CLASSIFICATION OF GRAVEL SAMPLES

For the purpose of this investigation, nine samples of about 200 kg of gravel were taken from different active quarries in an area 20 km long by 10 km wide. Five samples of sand of similar quantity were taken from the sand pits of the Al-Jahra area.

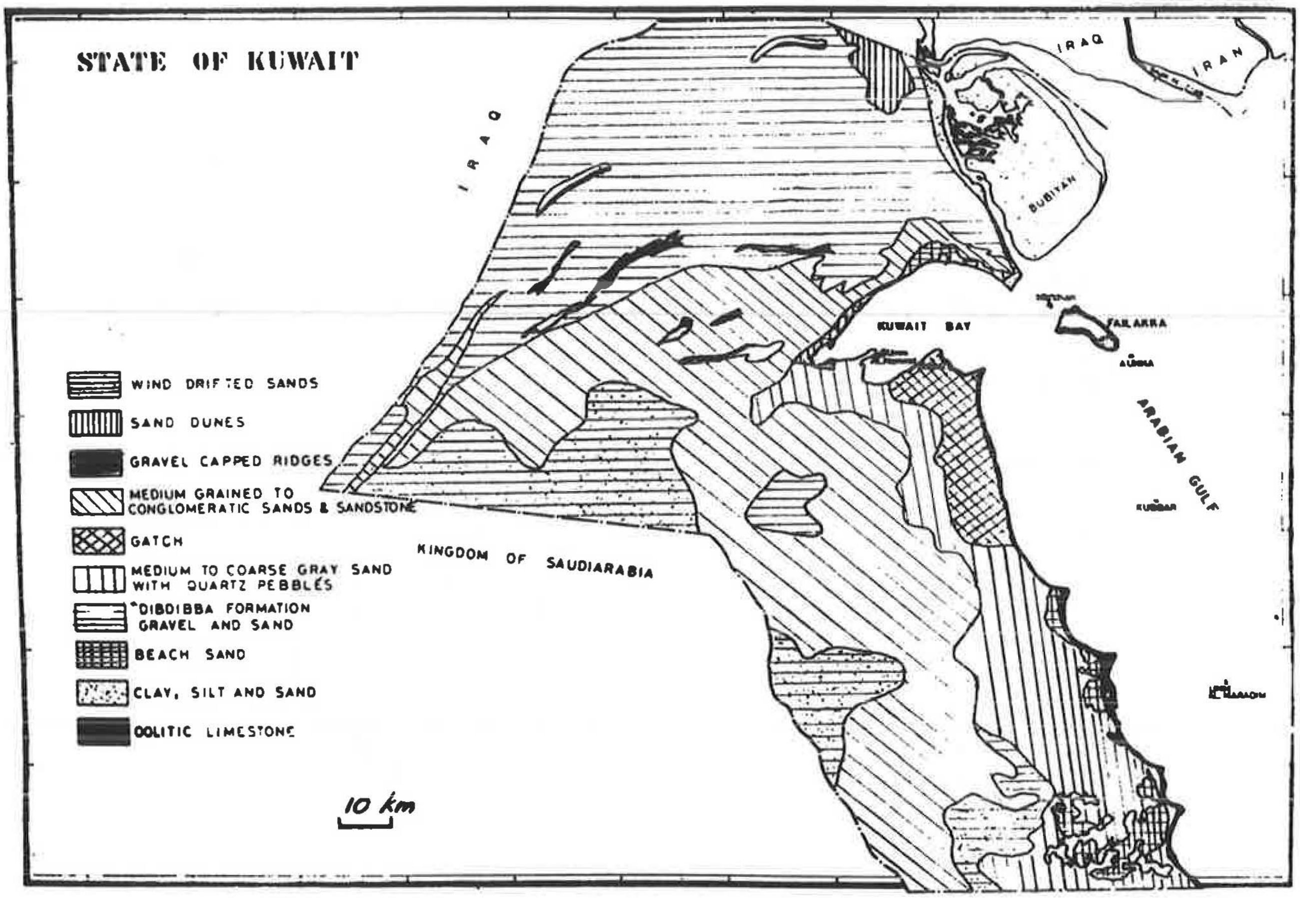

FIGURE 2 Gravel and sand formations of the Kuwait surface.

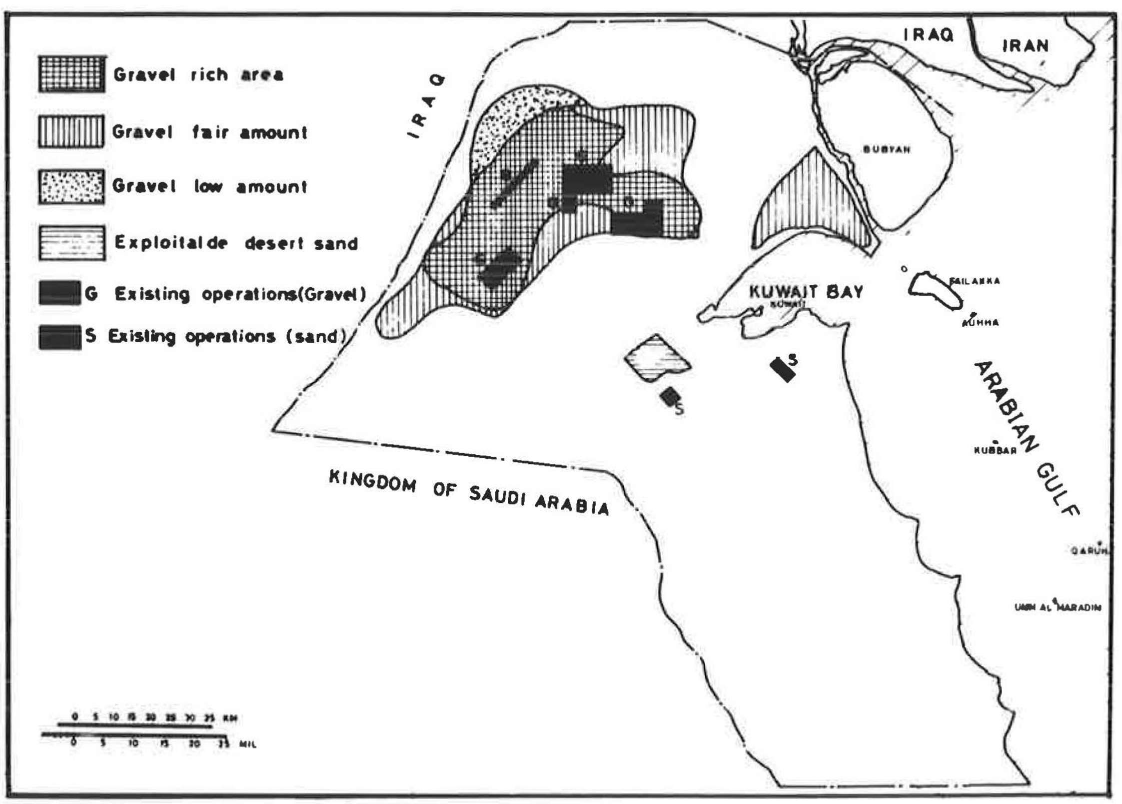

FIGURE 3 Exploitable gravel and sand areas.

Petrological classification of the samples facilitated their separation into eight distinct types, as shown in Figures 4-11. The approximate percentages of total aggregate comprised by each of these eight aggregate types are given in the following table:

Type	Approximate Proportion of Aggregate (%)
Quartz	31
Andesite	22
Felsite	14
Silicified serpentine	8
Cemented sand and gravel	8
Granite	8
Rhyolite	6
Basalt	3

TESTS ON GRAVEL

Two sets of laboratory tests were performed. The first set (A) consisted of tests performed on samples taken from each quarry. The second set (B) of tests was performed on the aggregates after grouping them into eight types according to the petrological classification.

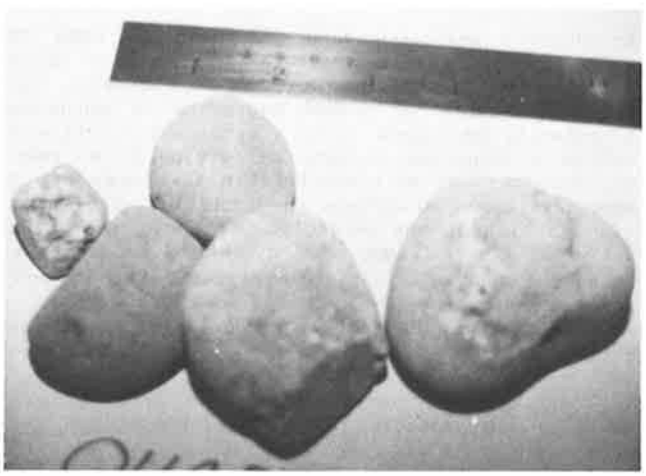

FIGURE 4 Quartz.

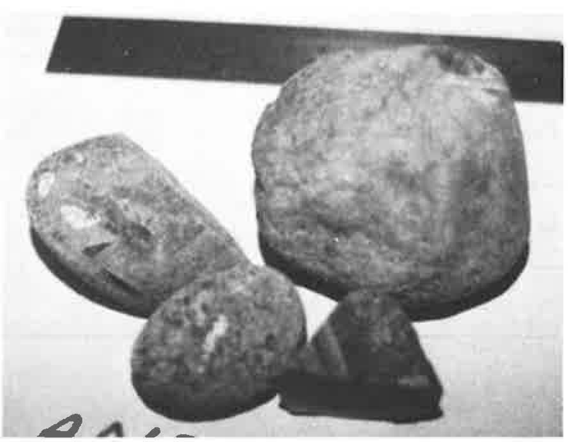

FIGURE 5 Andesite.

Set A

Tests for Chlorides and Sulfates

Soluble chlorides were determined volumetrically by Mohr's method (the silver nitrate-potassium chromate method). The acid soluble sulfates were determined gravimetrically by precipitation as barium sulfates (10). Results from eight randomly selected quarries in the area are given in Table 1.

From the data in Table 1 it can be seen that the highest chloride content was 0.0175 percent by weight of the coarse aggregate, which is within the

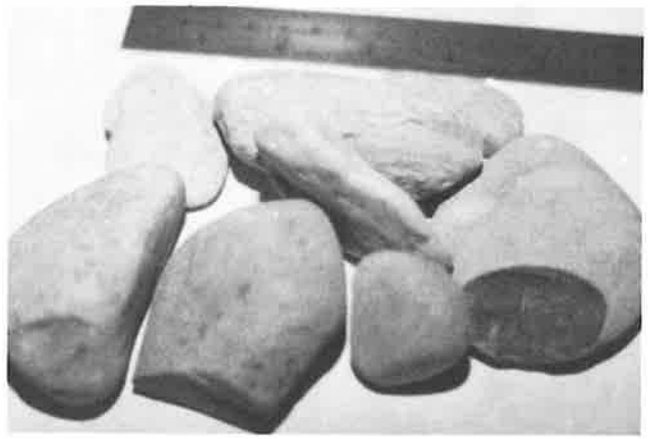

FIGURE 6 Felsite.

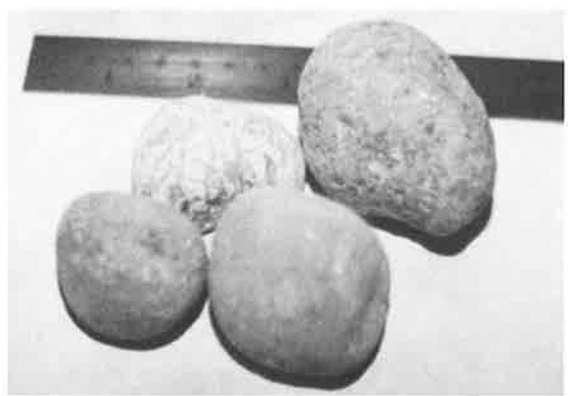

FIGURE 7 Silicified serpentine.

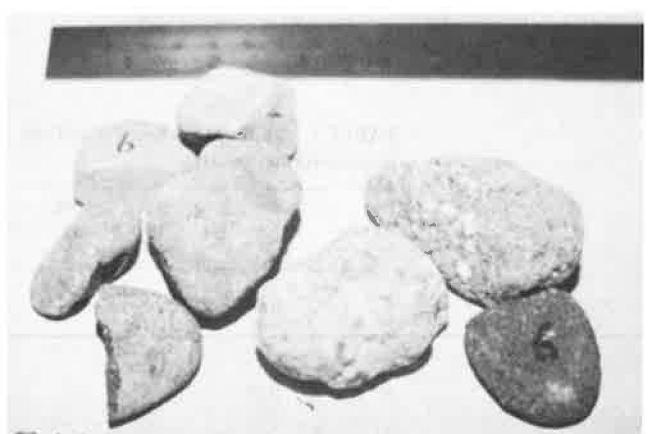

FIGURE 8 Cemented sand and gravel.

strictest limitation of 0.02 percent of Greater London Council (GLC) (11). It is also well within the much less severe limitation of the Building Research Establishment (12), which restricts the chloride content for a low risk of reinforcement corrosion to less than 0.4 percent of the weight of cement. This is equivalent to about 0.1 percent of the weight of coarse aggregate for a typical concrete mix (11).

The highest sulfate content recorded in this series was 0.35 percent by weight of the coarse aggregates. The average sulfate content for the eight pits was 0.14 percent. Both these values fall below the limit of 0.37 percent proposed by the Cement and Concrete Association for the case when even as high as 0.5 percent SO_3 is expected to be present in the fines (11).

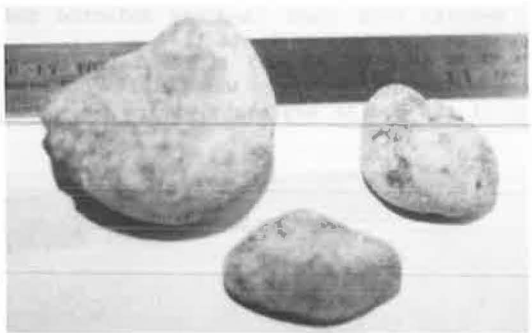

FIGURE 9 Granite.

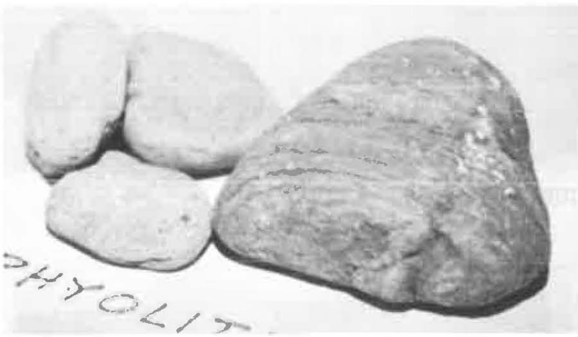

FIGURE 10 Rhyolite.

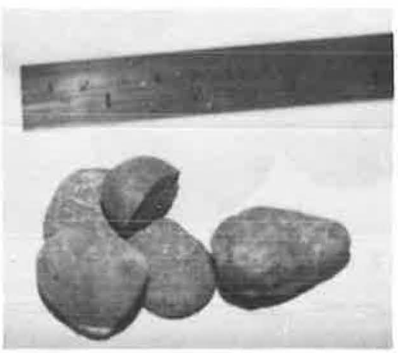

FIGURE 11 Basalt.

Tests for Organic Matter Content

These tests were performed according to ASTM C40 (ASTM Standard C40-66, Test for Organic Impurities in Sand for Concrete). The method is colorimetric. The acids in the sample are neutralized by a 3 percent solution of NaOH, prescribed quantities of aggregates, and the solution being placed in a bottle. The mixture is vigorously shaken to allow the intimate contact necessary for chemical action, and it is then left to stand for 24 hr, when the organic content can be judged by the color of the solution. The greater the organic content, the darker is the color.

The results indicated that the samples do not contain organic impurities.

Tests for Soundness of Aggregates

Soundness tests were done according to ASTM C88 (ASTM Standard C88-71a, Test for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate). A sample of graded aggregate is subjected alternately to immersion in a saturated solution of sodium or magnesium sulfate and drying in an oven. The formation of salt crystals in the pores of the aggregate tends to disrupt the particles. The reduction in size of the particles, as shown by a sieve analysis, after a number of cycles of exposure denotes the degree of unsoundness. The loss on sieves for unsound coarse aggregates is about 6 percent.

The results indicated the soundness of the aggregates (Table 1).

Tests for Determination of Potential Reactivity

Reactivity tests were performed according to ASTM C289 (ASTM Standard C289-71, Test for Potential Reactivity of Aggregates, Chemical Method). The method measures the reduction in the alkalinity of a normal solution of NaOH when placed in contact with pulverized aggregate at 80°C. The amount of dissolved silica is also determined by using a photometer and a series of solutions of known silica con-

TABLE 1 Summary of Results of Tests Performed on Aggregates Taken from Representative Quarries

Quarry No.	Soluble Chlorides (ppm)	Acid Soluble Sulfates SO_3 (ppm)	Soundness [total loss on sieves (%)]	Dissolved Silica (millimoles/L)	Reduction in Alkalinity (millimoles/L)
1	105	750	2.59	17.0	75
2	100	500	2.85	13.0	90
3	105	1,000	2.93	10.0	120
4	110	1,000	3.02	14.0	135
5	140	1,000	2.68	16.0	140
6	140	2,500	3.87	9.0	130
7	175	3,500	2.89	11.0	150
8	105	1,000	2.65	11.0	160

Note: ppm = parts per million.

centration varying from 0.0 to 0.5 millimoles/L. The result is plotted on a graph representing reduction in alkalinity versus silica dissolved. A potentially deleterious reaction is indicated if the plotted test result falls to the right of a specified boundary line.

The results, which are given in Table 1, indicate that the aggregates are considered innocuous and have no deleterious effects on concrete.

Set B

This set of tests was made on the aggregates after being grouped according to petrological classification. X-ray diffraction analysis and classical wet chemical analysis were done for each group. Figure 12 shows the results of x-ray diffraction, which indicate that the aggregates are composed mainly of quartz and feldspar with the presence of calcite and gypsum. The presence of mica is also indicated, although its quantity is believed to be small. This qualitative analysis was supplemented by analysis using classical methods of analytical chemistry, which revealed the composition given in Table 2.

It may be concluded from these results and from the estimation of the proportions of each type of gravel that the main oxide percentages present in the total coarse aggregates that have been surveyed are as follows:

Oxide	Percent
Silicon dioxide (SiO_2)	76.21
Iron oxide (Fe_2O_3)	3.67
Aluminum oxide (Al_2O_3)	6.63
Calcium oxide (CaO)	4.44
Magnesium oxide (MgO)	1.07
Sodium oxide (Na_2O)	2.26
Potassium oxide (K_2O)	2.50
Sulfur trioxide (SO_3)	0.115
Loss on ignition	2

Thus the sulfates content was 0.115 percent of the weight of the coarse aggregates. This value is well within the generally adopted safe limit value of 0.4 percent (13).

ANALYSIS OF SAND

Although sand is abundant in almost all regions of Kuwait, it is usually contaminated with sulfates, chlorides, calcite, silt, and clay. As shown in Figure 2, an extremely unsuitable sand called gatch is found in areas in and surrounding the capital. Gatch is a marine-deposited sandy soil. The word gatch is Iranian meaning gypsum. However, the sand that could be used for construction purposes can be divided into the following groups (14): (a) dredged seashore sand, (b) Jahra sand, (c) desert sand, and (d) sand from windblown sand dunes.

Group a, although the best as far as grading is concerned, is more difficult to obtain and is much less abundant and needs more extensive processing. Group c contains too much fines, and group d is a single-grained sand. Group b, however, can be classified as type 2 or type 3 according to British Standard 882 (15), and thus it is suitable for concrete work. Jahra sand is the sand that is more widely used in Kuwait because it is the most suitable sand for construction, and because the area is the only area left for sand exploitation and is still not restricted by different government schemes or environmental considerations.

The sand of Jahra belongs to the Miocene-Pliocene age. Its thickness is between 6 and 14 m and consists mainly of brown to greyish quartz grains (9). The pit area is about 20 km inland, and the exploitable layers lie under an overburden that is less than 2 m thick. All excavation activities occur in sections well above the brackish water level; thus there is no contamination from salt deposition. The amount of fines passing the No. 200 sieve is between 2 to 24 percent and is mostly silt and clay. Thus efficient mill washing will ensure separation of fines and produce sand that is suitable for good quality concrete.

Analysis on five samples taken from different parts of the area was performed. The results obtained from chemical analysis and potential reactivity are given in Table 3. Samples 1 and 2 were from untreated sand, whereas samples 3, 4, and 5 were taken from washed sand ready for use. It may be concluded from the results that washing the sand had only a small effect on the main chemical structure. This is expected because this sand is not a seashore sand where water-soluble salts like the chlorides of sodium and potassium, or the sulfates of magnesium, sodium, and potassium, are expected to be present.

The salts that are present in this inland sand, which is high above the brackish water level, are mainly gypsum and calcite (sulfates and carbonates of calcium) that are not water soluble. Gypsum and calcite constitute the predominant part of the fines content (passing the No. 200 sieve), the quantity of which varies from 2 to 24 percent of the weight of sand (8). Thus the beneficial effects of washing are the removal of fines and of adhering particles of gypsum by the shear mechanical factor involved in the washing process. These effects are demonstrated in the results of the tests, where the average content of sulfates in the washed samples was lower than it was in the unwashed samples.

However, it should not be assumed that prolonging or repeating the washing process could get rid of the sulfates. Contractors in Kuwait often make the mistake of repeating the washing process of a rejected supply of sand, thus losing time, effort, and money. What they should do is change the site or the depth where their excavation was made. This reasoning applies as well to the chlorides, and it is clear that they are found in minor amounts in this type of sand.

Potential reactivity tests made according to ASTM C289 indicated that the sand is considered innocuous and has no deleterious effect on concrete.

CONCLUSIONS

This study demonstrated that the basic indigenous materials used for concrete production in Kuwait are of good quality and are suitable for producing good quality concrete. Thus it would be of importance to contractors and consultants who operate in that part of the Middle East to direct their efforts toward the strict control of concrete mix design and concreting practices that appear to be the factors more responsible for the extensive deterioration that is observed in this area. Washing of the aggregates is important for getting rid of fines and clay contamination, but it should not be thought of as the major remedy for the problems of concrete in Kuwait.

ACKNOWLEDGMENT

The study reported in this paper is part of a continuing research on the causes of concrete deterioration in Kuwait. The research is sponsored by the Science Research Council of Kuwait University.

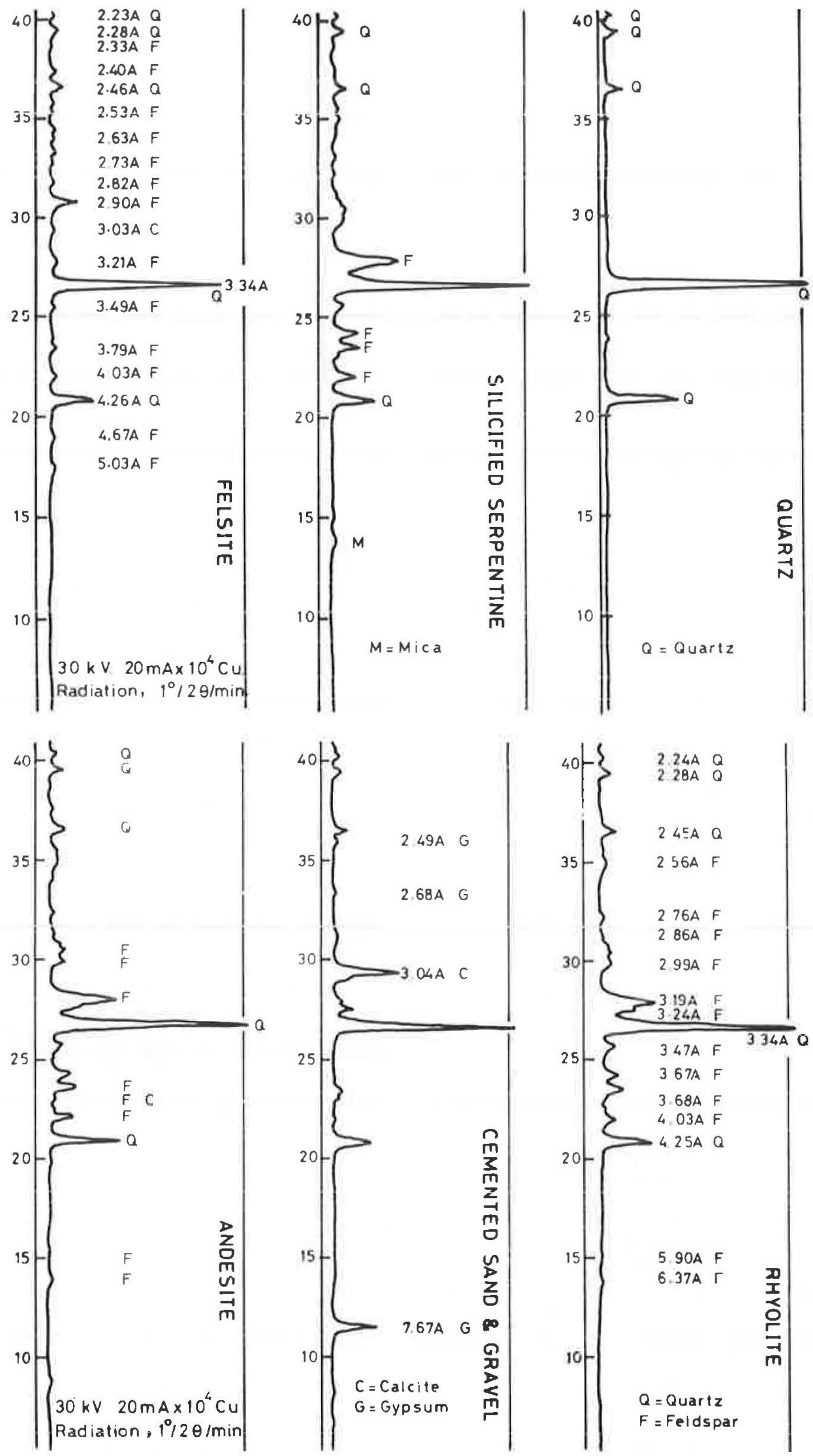

FIGURE 12 X-ray analysis of main types of coarse aggregates.

TABLE 2 Results of the Quantitative Chemical Analysis of Coarse Aggregate

Classification	Silica SiO_2 (%)	Ferric Oxide Fe_2O_3 (%)	Aluminium Oxide Al_2O_3 (%)	Magnesium Oxide MgO (%)	Calcium Oxide CaO (%)	Sodium Oxide Na_2O (%)	Potassium Oxide K_2O (%)	Sulfur Trioxide SO_3 (%)	Loss on Ignition (%)
Quartz	97.00	0.08	0.28	0.72	1.50	0.00	0.00	0.00	0.00
Andesite	72.26	4.49	9.94	1.50	2.79	4.87	1.89	0.00	0.30
Felsite	61.48	5.22	12.22	1.62	4.76	4.00	9.65	0.00	0.65
Silicified serpentine	70.99	3.59	11.67	0.11	2.17	6.06	5.00	0.00	0.95
Cemented sand and gravel	43.38	0.40	0.28	0.96	27.00	-	-	1.44	21.15
Granite	67.97	7.36	12.87	1.77	3.51	1.73	3.59	0.00	0.26
Rhyolite	82.86	5.80	9.35	1.00	0.00	0.00	0.00	0.00	0.75
Basalt	69.38	22.19	3.14	0.21	2.66	0.23	1.52	0.00	0.19

TABLE 3 Results of Quantitative Chemical Analysis of Sand

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Oxides (%)					
SiO_2	88.30	79.30	85.00	86.35	87.19
Fe_2O_3	0.45	1.28	1.46	1.18	1.25
Al_2O_3	4.78	2.89	5.67	4.96	4.85
CaO	3.86	8.65	3.69	3.82	3.55
MgO	0.38	0.55	0.85	0.75	0.59
SO_3	0.35	0.38	0.025	0.27	0.025
Cl^-	0.025	0.015	0.001	0.02	0.001
Loss on ignition	1.68	6.25	1.83	1.79	1.64
Potential reactivity (millmoles/L)					
Soluble silica	41.0	40.0	45.0	52.0	51.0
Reduction in alkalinity	285	305	315	330	310

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