

Riyadh Sands and their Effect on Concrete Performance

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Abstract. A physical and geological study of Riyadh sands was made on samples collected from crushing plants located in quarrying sites around Riyadh. An experimental study, following ASTM Standards, of the effects of these properties on the performance of fresh and hardened concrete was also carried out.

Petrographic analysis showed that the fine aggregate particles are hard and in general subangular to subrounded and more elongated than spherical in shape. A large number of samples showed a presence of very fine sand and silt in them. The aggregates basically are classified as limestone rocks of various types. A rare occurrence of dolomitic limestone was discovered in one sample.

Mineralogical analysis showed a presence of trace amounts of clay minerals in some samples of which a few had montmorillonite. Non-clay minerals present included calcite, silica, quartz, feldspar, limonite, iron oxide, hematite and gypsum in two samples in rare amount.

Introduction

Aggregates for concrete in the city of Riyadh are obtained from various quarrying sites around the city. The quarrying sites of Wadi Laban, Salbukh Road, Al-Kharj Road and Khurais Road are shown in Fig. 1.

The natural aggregates available in the quarries are processed for grading. Crushed stone aggregates are also processed in the plants at these sites. Both the natural and crushed stone fine aggregates contain excessive fraction of very fine sands (*i.e.* passing # 200 mesh) and are marketed in unwashed state or after washing.

In all, thirty six samples from the four quarrying sites were subject to lithologic and petrographic analyses. Twenty three of these samples were analyzed for clay-minerals by x-ray diffraction. Based on the similarity of petrological properties of the

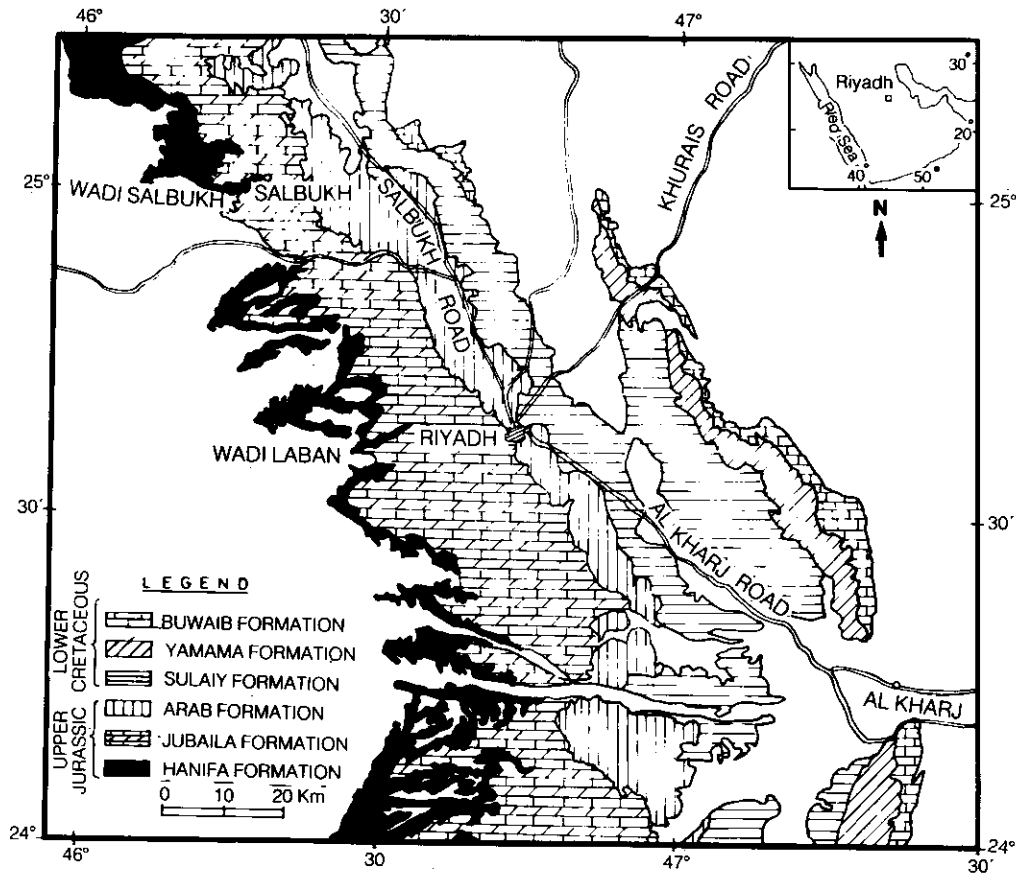


Fig. 1. Quarrying sites around Riyadh

samples from all the sites, only six samples from Wadi Laban were employed for the tests to determine the physical properties of the sands and their effects on the properties of fresh and hardened concrete.

Geologic Investigation

The geologic formations around Riyadh, where the quarrying sites are located, are part of the Arabian shelf which borders the basement complex of the Arabian shield [1]. In general, the exposed bed rock has moderately weathered surfaces.

The Wadi Laban and Salbukh samples were from the Jubaila and Hanifa carbonate formations. Jubaila (Upper Jurassic) is generally composed of argillaceous,

dolomitic limestones [1,2], while Hanifa (Upper Jurassic) mainly consists of carbonate lithofacies, comprising of argillaceous, arenaceous, reefal and oolitic limestones, intercalated with shale beds [3,4]. The Khurais Road samples are from Buwaib (Lower Cretaceous) formation and are generally composed of arenaceous, argillaceous and dolomitic limestones and chalky and sandy marls [5]. The Kharj Road samples were from the Buwaib and Yamama formations. Yamama (Lower Cretaceous) consists of aphanitic and calcarenitic limestones, and calcarenities and calcareous sandstones [1].

Rock Type

In general, the aggregate grains consist of limestone and sandy, marly, chalky, argillaceous and a few ferruginous limestones. Dolomitic limestone was also present in one sample from Kharj Road. The percent samples of the various rock types are presented in Fig. 2.

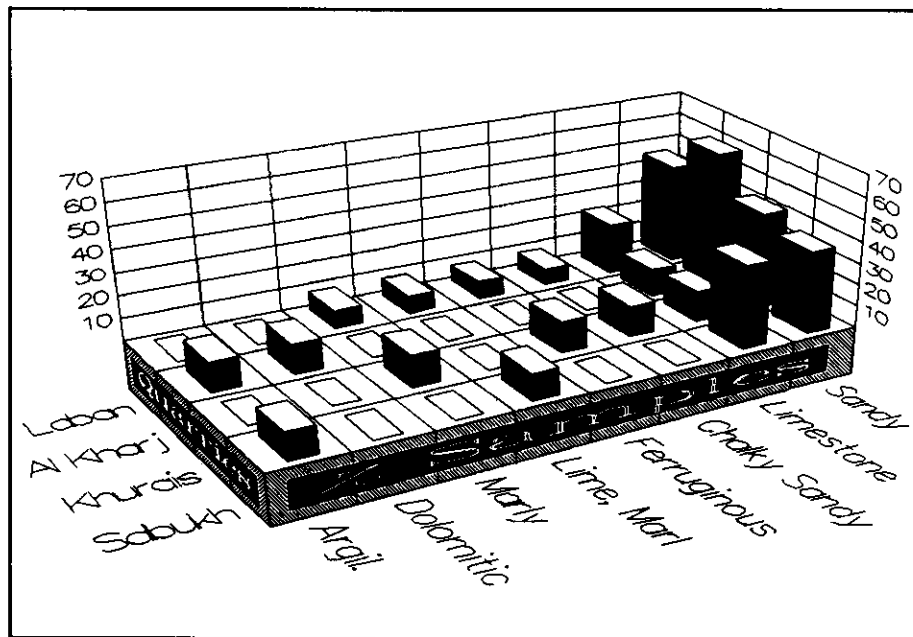


Fig. 2. Percent samples of limestone rock type

Roundness

Particles of various sizes were sorted out according to Krumbein's Pebble Roundness Chart [6] and classified according to the particle roundness scale developed by Powers [7] which is shown in Plate 1. In general, particles range in roundness from rounded to angular. The Wadi Laban and Khurais samples are classified to be more sub-angular to angular, Kharj to be more rounded to sub-rounded while Salbukh to be more sub-rounded to sub-angular. The percent samples in various roundness range are presented in Fig. 3.

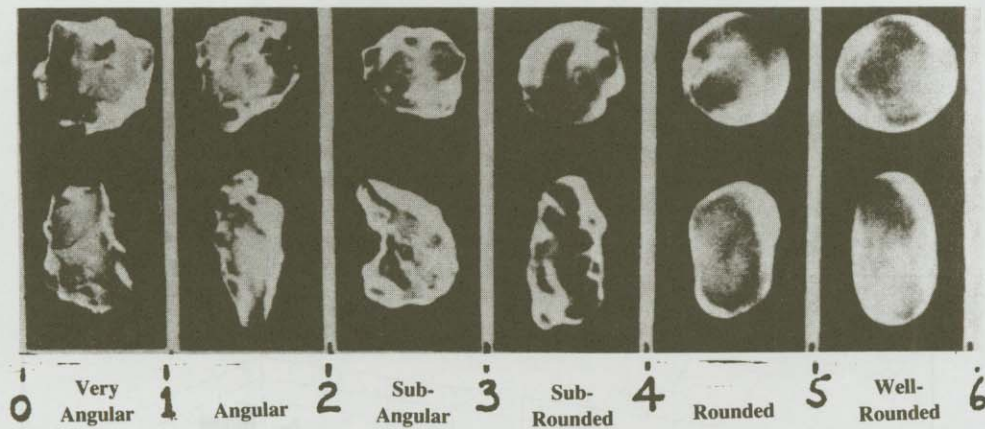


Plate 1. Particle roundness scale [7]

Particle Shape or Sphericity

The classification of particle shape according to Zingg [8] is shown in Plate 2. The majority of particles in the Wadi Laban samples are either flat (blade) or elongated (rod like) in shape. Samples from the other areas have particles spherical in shape in addition to being flat and elongated. Fig. 4 presents percent samples of various sphericity types. Perception of roundness and shape of the particles may be formed from photographs of the fractions retained on various sieves as shown in Plate 3.

Aggregate Size

The grain size of aggregates was determined in accordance with Wentworth grade scale [9]. This scale classifies sizes above 64 mm as cobbles, 4 to 64 mm as pebbles,

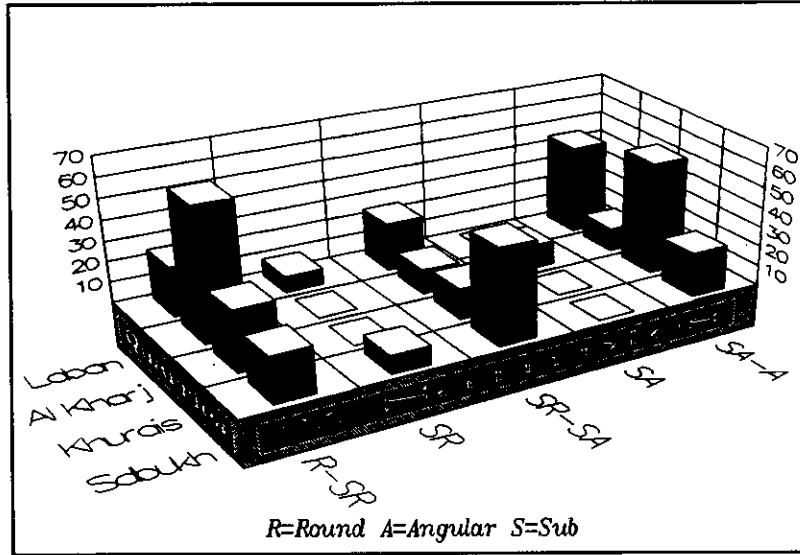


Fig. 3. Percent samples in roundness ranges

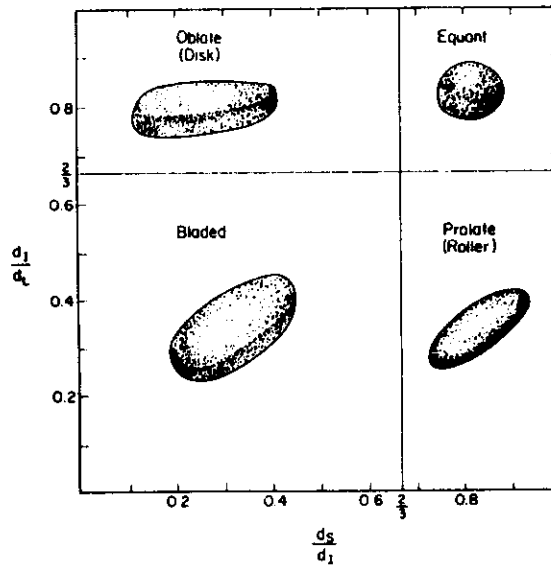


Plate 2. Particle shape classification [8]

Note: d_1 , d_2 and d_3 are the longest, intermediate and shortest mutually perpendicular dimensions of a particle

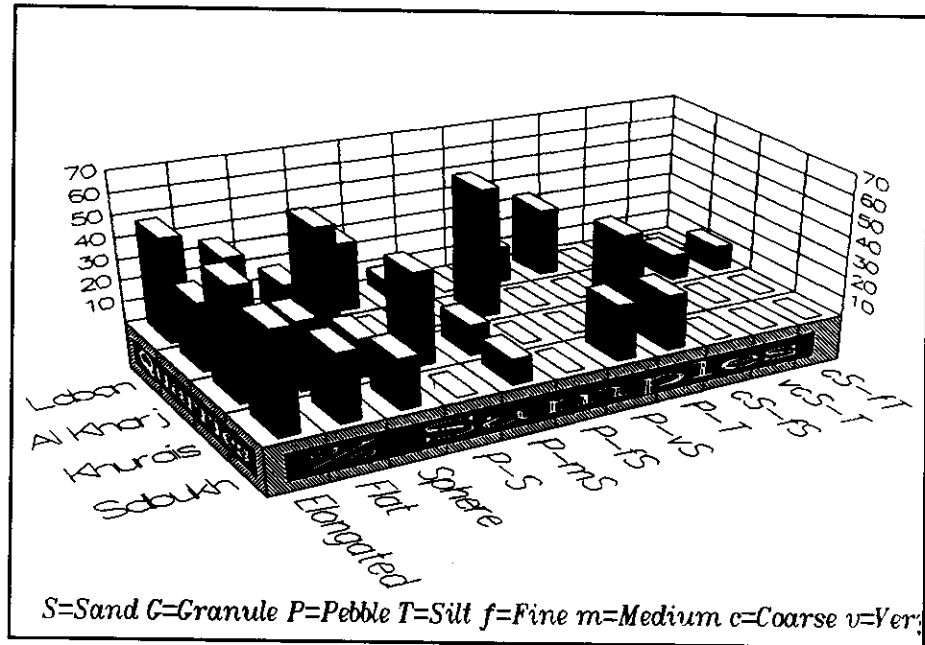


Fig. 4. Percent samples of sphericity type

bles, 2 to 4 mm as granules, 1 to 2 mm as very coarse sand, 0.5 to 1 mm as coarse sand, 0.25 to 0.50 mm as medium sand, 0.125 to 0.25 mm as fine sand, 0.0625 to 0.125 mm as very fine sand, 0.0039 to 0.0625 mm as silt and below 0.0039 mm as clay. The percent samples in various size ranges are presented in Fig. 5.

Hardness

In general, the particles in the samples have a hardness of 3 to 5 on Moh's hardness scale [10]. The percent samples in various hardness ranges are presented in Fig. 6.

Mineral Analysis

Clay Minerals

X-ray diffraction analysis according to Brown's procedure [11] indicated the presence of trace amount of clay minerals in all the samples from all the sites. Kaoli-

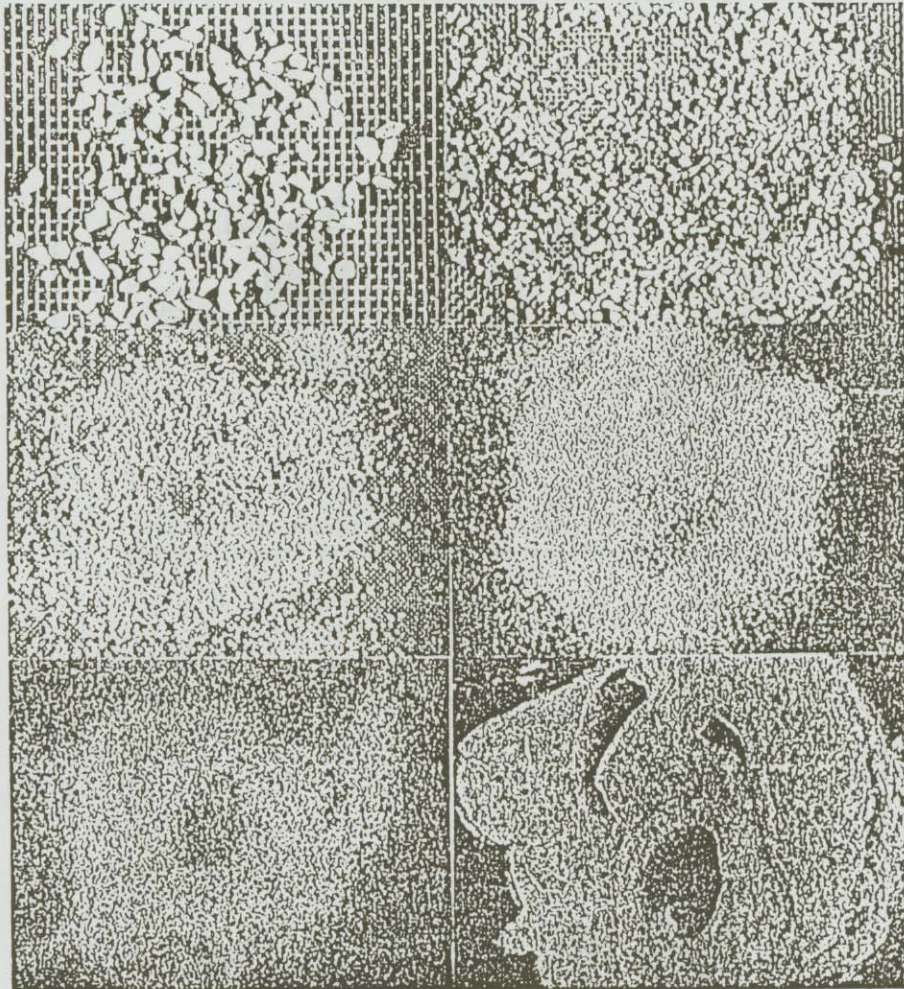


Plate 3. Fractions retained on various sieves

nite and illite were present in all the samples while montmorillonite was found in three samples from Kharj Road.

Non-Clay Minerals

The non-clay minerals present in the samples were calcites, silica, quartz, feldspar, limonite, iron oxide, hematite and gypsum. One sample each from Wadi Laban (13 samples) and Khurais (7 samples) showed presence of gypsum in rare amount.

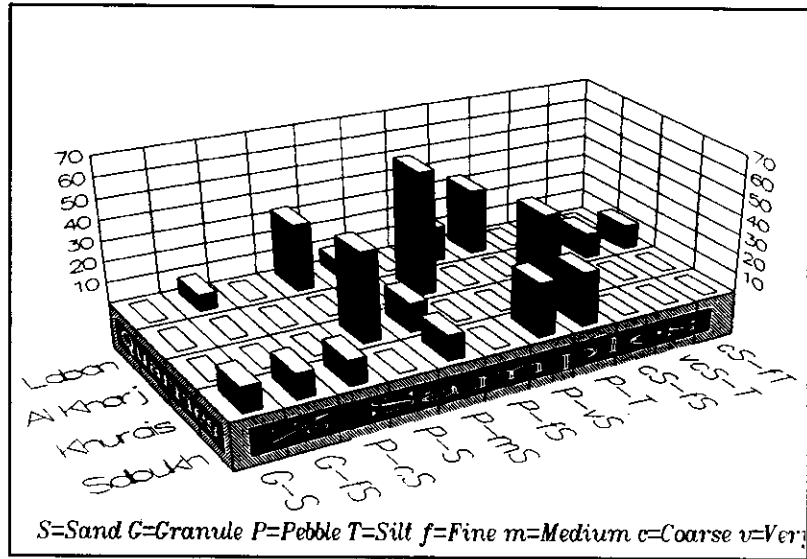


Fig. 5. Percent samples in size ranges

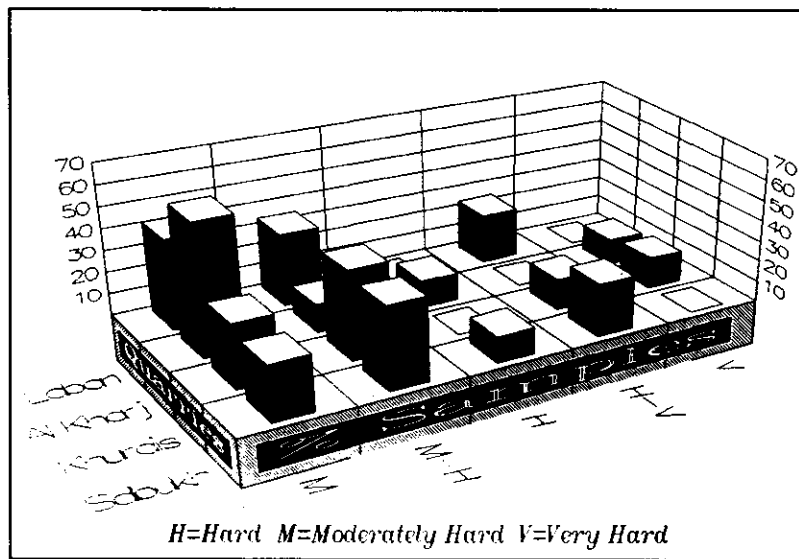


Fig. 6. Percent samples in hardness ranges

Physical and Material Property Analyses

The field and laboratory investigations made for this study were reported in details in Ref. [12].

Physical property tests were carried out, as per ASTM procedures, on the six samples obtained from Wadi Laban and a silica sand sample obtained from Khurais Road. The sand samples were designated as shown in Table 1.

Table 1. Sand sample and mix codes

Source	Sand sample code	Mix code
Al-Draiss plant	WS-01	WS-01-M1
		WS-01-M2
		WS-01-M3
	US-02	US-02-M1
		US-02-M2
		US-02-M3
Rea Saudi Arabia plant	WS-03	WS-03-M1
		WS-03-M2
		WS-03-M3
	US-04	US-04-M1
		US-04-M2
		US-04-M3
Al-Sa'awy plant	WS-05	WS-05-M1
		WS-05-M2
		WS-05-M3
	US-06	US-06-M1
		US-06-M2
		US-06-M3
Khurais Road	SS-07	SS-07-M1
		SS-07-M2
		SS-07-M3

Note: WS and US in sample code refer to washed and unwashed sands.

The results of sieve analysis on the six samples along with the ASTM C33 limits are shown in Fig. 7. Fineness moduli as low as 1.68 and as high as 3.42, and a sand equivalent percentage ranging from a low of 14.0 to a high 81.0 were measured.

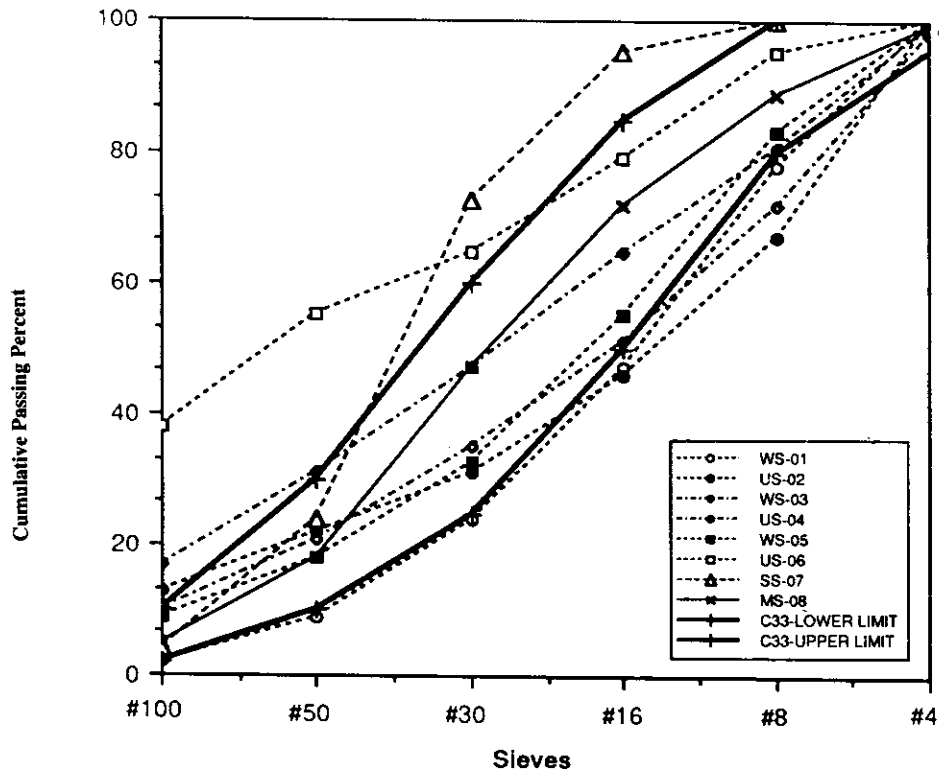


Fig. 7. Grading curves of crushed stone sand samples

The results of various physical property tests on the six samples are presented in Table 2. The same test results on the silica sand sample are also shown there.

Three concrete mixes were adopted consisting of cement:sand:coarse aggregate ratios by weight of 1:2:4, 1:1.7:3.4 and 1:1.45:2.90 and designated as mixes M1, M2 and M3 respectively. The mixes were designed for a slump of 75 ± 10 mm.

For sand of standard grading and maximum coarse aggregate size of 19 mm the mixing water required, as per ACI procedure, is 202 kg per cubic meter of concrete [13]. However, for the sands used in this study, the actual quantity of mixing water required for obtaining the slump of 75 mm varied from sample to sample. The actual mixing water quantities including absorption by the aggregates are given in Table 3. The coarse aggregate used was crushed limestone with a maximum size of 19 mm and was obtained from one crusher plant in Wadi Laban.

Table 2. Physical properties of the sand sample

ASTM design.	C29	C128	C136	C117	C40	C88	C142	D2419	-	-
Sand sample code	Unit weight kg/m ³	Bulk S.Gr. (SD) ⁽¹⁾	Absorption percent	Fineness modulus	Minus # 200 percent	Organic impurities percent	Sulfate sound. percent loss	Clay Lump & Friable percent	Sand equivalent percent	Voids percent
WS-01	1419	2.57	2.09	3.42	4.0	None	2.27	0.30	81.0	44.0
US-02	1462	2.50	2.36	3.18	29.0	None	1.96	0.33	34.0	42.0
WS-03	1404	2.51	2.38	3.14	8.0	None	1.70	0.10	71.0	47.0
US-04	1551	2.47	2.63	2.60	20.0	None	1.16	0.27	29.0	38.0
WS-05	1304	2.45	3.68	3.03	9.0	None	0.81	0.30	49.0	46.0
US-06	1536	2.41	3.52	1.68	17.0	None	3.94	3.73	14.0	40.0
SS-07	1710	2.63	0.45	2.06	1.5	None	-(⁵)	-	90.0	39.0
C33 std				2.72	5 max. ⁽²⁾	1 max.	10 max. ⁽³⁾ 15 max.	3 max.	-	38-50 ⁽⁴⁾

(1) Surface-dry bulk specific gravity.

(2) 7% max. for stone sand.

(3) 10% for sodium sulfate and 15% for magnesium sulfate solutions.

(4) Typical values suggested in ACI-Guide [4].

(5) Not applicable

Table 3. Effect of sands on properties of fresh concrete

Sand sample code	F.M.	Minus # 200 percent	Mixing water kg/m ³	W/C	Slump mm	Total Bleed Water	
						percent	ml/cm ²
Cement content = 300 kg/m ³ of concrete							
WS-01	3.42	0.33	207	0.69	63.0	-	-
US-02	3.18	4.17	264	0.88	83.0	1.23	0.079
WS-03	3.14	1.74	234	0.78	76.0	-	-
US-04	2.60	3.63	235	0.78	76.0	1.33	0.077
WS-05	3.03	1.63	212	0.71	76.0	1.42	0.062
US-06	1.68	7.40	230	0.77	83.0	1.61	0.097
SS-07	2.06	1.50	204	0.68	76.0	2.93	0.089
MS-08	2.70	1.50	234	0.78	70.0	1.54	0.054
Cement content = 350 kg/m ³ of concrete							
WS-01	3.42	0.33	226	0.65	76.0	2.14	0.127
US-02	3.18	4.17	265	0.76	76.0	0.92	0.059
WS-03	3.14	1.74	210	0.60	83.0	1.72	0.079

Table 3. Contd.

Sand sample code	F.M.	Minus # 200 percent	Mixing water kg/m ³	W/C	Slump mm	Total Bleed Water	
						percent	ml/cm ²
Cement content = 300 kg/m³ of concrete							
US-04	2.60	3.63	253	0.72	76.0	0.71	0.045
WS-05	3.03	1.63	219	0.62	83.0	0.71	0.040
US-06	1.68	7.40	236	0.67	76.0	1.46	0.085
SS-07	2.06	1.50	211	0.60	76.0	2.35	0.089
MS-08	2.70	1.50	230	0.65	76.0	1.46	0.055
Cement content = 400 kg/m³ of concrete							
WS-01	3.42	0.33	229	0.57	76.0	3.66	0.190
US-02	3.18	4.17	272	0.68	76.0	1.35	0.081
WS-03	3.14	1.74	217	0.54	83.0	1.80	0.073
US-04	2.60	3.63	237	0.59	76.0	0.80	0.036
WS-05	3.03	1.63	226	0.56	89.0	1.06	0.057
US-06	1.68	7.40	232	0.58	83.0	1.00	0.059
SS-07	2.06	1.50	211	0.53	83.0	2.41	0.069
MS-08	2.70	1.50	229	0.57	83.0	1.19	0.051

- Notes: 1) The missing values of total bleed water in samples SW-01 and WS-03 could not be measured.
 2) Fineness modulus (F.M.) and Minus # 200 percent were determined by ASTM C 136.
 3) Mixing water reported includes water absorbed by the aggregates.

Table 3 also reports the properties of fresh concrete, including slump and bleeding, on the seven sand samples of Table 1 and a median sand sample (MS-08). The median sand was obtained by combination of different fractions in order to attain an average grading of ASTM C33.

The regressed relationship between mixing water and material minus # 200 in the sand is shown in Fig. 8.

Fresh Concrete

Effect of Sand Gradation

Table 2 and Fig. 7 indicate that all washed sands are very coarse. The effect of washing rendered these sands to be coarser by removing most of the finer than # 50 material. This is clearly indicated by a comparison of the percentages passing # 50 to # 200 in the washed and unwashed samples. Unwashed sands on the other hand are very fine and contain large amounts of fine material up to 29 percent in some sam-

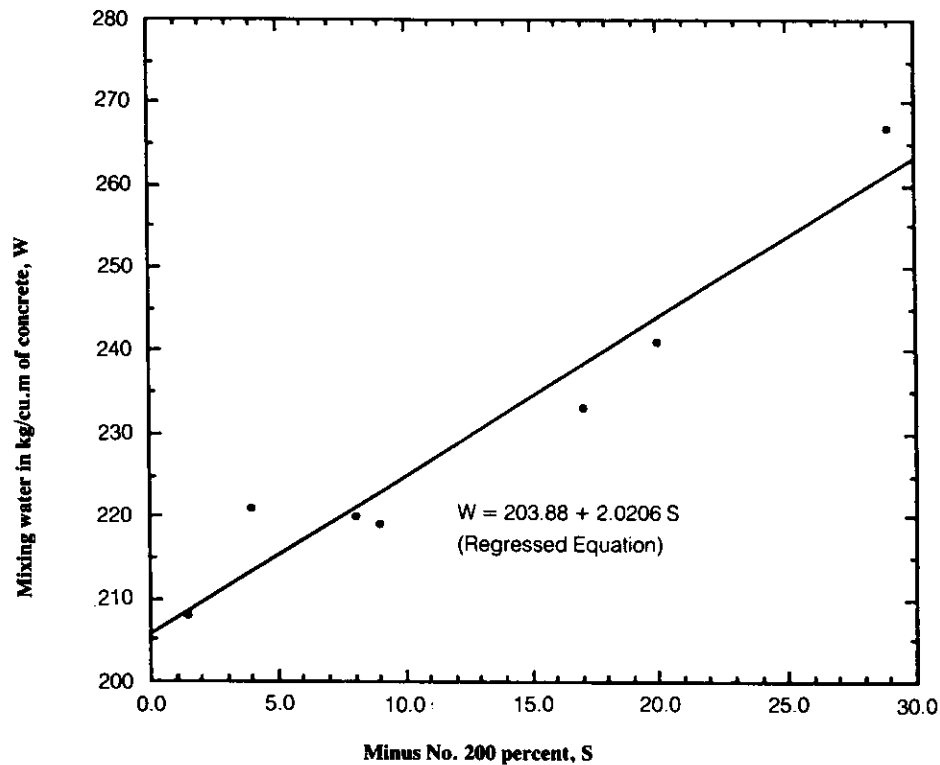


Fig. 8. Relationship between mixing water and minus No. 200 percent contents

ples. In the washed samples, the percentage of fine material is reduced to a maximum of 9 percent which is still in excess of the specified ASTM limits for both natural and crushed stone sands.

The excessive amounts of fine material in the unwashed Riyadh sands have a pronounced effect on the workability and bleeding of concrete. These two properties of concrete are mainly affected by mixing water content which in turn is influenced by the large surface area per unit volume of fine material in the aggregate. From Table 3 it can be seen that the average mixing water content required to attain an average slump of 75 mm in concretes made with unwashed sand was 12 percent higher than that used for the concrete made with washed sands. Moreover, considering the mixing water used in the silica sand mix as a basis, the washed sand concrete required 6 percent more water while the unwashed sand concrete required 12 to 28 percent more water to produce the same slump of 75 mm.

The high percentage of very fine sand, however, has a beneficial effect on the bleeding of concrete. This can be seen from Table 3 which indicates the average

bleeding in the case of unwashed sand concrete to be 45 percent of that of silica sand concrete. In the case of washed sand concrete, the value is 75 percent of the silica sand concrete.

Effect of Particle Shape

The petrographic analysis showed the Wadi Laban samples to be mostly classified as sub angular to angular with the majority of particles being either flat or elongated in shape. The influence of this particle shape is reflected in the high void contents shown in Table 2 and consequently the high demand for mixing water to provide the required consistency or workability.

Hardened Concrete

The compressive and flexural strength test results are shown in Table 4. The influence of aggregate grading and particle shape is reflected in the performance of hardened concrete by their influence on the mixing water requirement. The relatively higher mixing water required to produce the desired slump of 75 mm in the concrete mixes incorporating unwashed sand resulted in higher water-cement ratio than in the washed sand mixes (Table 3). High water-cement ratio adversely affected the strength and resulted in lower compressive and flexural strengths as is indicated in Table 4.

Conclusions

Petrographically, Riyadh sands are basically limestones of various types, largely elongated and sub-angular in size and shape. One sample showed presence of dolomitic limestone which is recognized as a cause of alkali-aggregate reactivity. Clay contents are in traces only. The amounts of very fine sand (passing # 200) in unwashed sands may be as high as 29 percent. Very fine sand in this excessive amount creates high water demand and adversely influences the workability of fresh concrete and strength of hardened concrete. Unwashed sands, therefore, are not recommended for the production of concrete. The washed sands have a grading far from the ideal with predominance of coarse fractions. Therefore, the flat and elongated particle shape of the Wadi Laban washed sand increases the water demand to attain a specified slump.

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Table 4. Compressive and flexural strength results

Mix code	Compressive strength kg/cm ²		Flexural strength kg/cm ²	
	Test	Average	Test	Average
WS-01-M1	147.0		30.0	
WS-03-M1	127.0	166.0	27.0	30.7
WS-05-M1	224.0		35.0	
US-02-M1	134.0		20.0	
US-04-M1	196.0	156.7	24.0	21.0
US-06-M1	140.0		19.0	
WS-01-M2	216.0		39.0	
WS-03-M2	231.0	223.0	39.0	37.0
WS-05-M2	223.0		33.0	
US-02-M2	168.0		29.0	
US-04-M2	214.0	182.3	26.0	26.0
US-06-M2	165.0		23.0	
WS-01-M3	239.0		46.0	
WS-03-M3	284.0	258.7	49.0	43.3
WS-05-M3	253.0		35.0	
US-02-M3	224.0		33.0	
US-04-M3	239.0	223.7	24.0	29.7
US-06-M3	208.0		32.0	

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رمال الرياض وأثرها على أداء الخرسانة

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ملخص البحث. يشتمل هذا البحث على دراسة فيزيائية، وجيولوجية أجريت على عينات من رمال الرياض تم الحصول عليها من محاجر الرمل حول مدينة الرياض. كما وقد اشتملت الدراسة أيضاً على تجارب تبعا للمواصفات الأمريكية لدراسة خواص هذه الرمال على أداء الخرسانة الطازجة والمتصلدة.

وقد بينت التحاليل البتروجرافية أن جسيمات الرمال صلدة عموماً وتتراوح من حيث الشكل من تحت الزوي إلى تحت المستديرة غير أنها متطاولة أكثر من أنها كروية وقد بين عدد كبير من العينات وجود رمال ناعمة جداً وأيضاً غرين، وقد صنفت الرمال على أنها من أصل حجري جيرى ذي أنواع متعددة. وقد تبين أيضاً وجود حجر دولوميت الجير في إحدى العينات.

وبينت التحاليل المعدنية وجود آثار لمعادن الطين في بعض العينات والتي كان بعضها يحتوي على المونتمورلونيت. وقد احتوت المعادن غير الطينية على الكالسيت والسيليكات والكوارتز والفلدسبار واللايمونيت وأكسيد الحديد ونخام الحديد (الهيئات). وقد اتضح وجود الجبس بكميات قليلة في عينتين.