CORRELATION OF PROPERTIES OF IRAQI LIMESTONE

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Test results obtained on limestone from different locations were used to investigate the relations of properties of limestone. A relation was found between abrasion wear obtained in the Los Angeles abrasion test and each of the following: compressive strength, impact value, and specific gravity. A nomographic solution for the physical properties is presented; once one of the properties is known, the other properties can be estimated by using the nomograph. An investigation was made of the relation between abrasion wear and chemical composition, and no significant relation was found.

• CALCITIC and dolomitic limestone is widely distributed in various regions of Iraq. The formation of limestone is divided into 3 groups according to their locations, as shown in Figure 1 (1, 2):

1. West of the Euphrates from the Syrian border to south of Samawa,
2. East of the Tigris from Mosul in the north to south of Kafri, and
3. The mountainous region in Sulaimania and Arbil.

Limestone has diverse uses in industry, agriculture, and construction. In the field of civil engineering, limestone is used for manufacturing materials such as portland cement and lime; it is also used as a building stone and as crushed aggregate for highway bases.

The properties of limestone are determined in a number of physical and chemical tests. Some of these tests are tedious and difficult to perform; others are time-consuming. The purpose of this paper is to present a nomographic solution correlating the physical properties of limestone. The values of other properties can be estimated if the value of any one of the following is known: Los Angeles abrasion (percentage of wear), compressive strength, impact value, apparent specific gravity, and bulk specific gravity.

MATERIALS

Eighteen samples of limestone from different locations were obtained and tested, as discussed below, by the Building Research Centre (3). The method prescribed in ASTM D 75-59 for sampling was adopted.

Los Angeles Abrasion Test

The Los Angeles abrasion test was carried out according to ASTM C 131; gradation A was used. The percentage of abrasion wear of the aggregates was found after 500 revolutions at a speed of 30 to 33 rpm with 12 steel spheres.

Compressive Strength Test

The compressive strength of limestone was found by crushing 7.5-cm cubes cut from pieces not smaller than 15 × 15 × 10 cm in size. A universal testing machine with a rate of loading of 1.25 cm/min was used. The average of 3 cubes was determined for each limestone sample tested.

Publication of this paper sponsored by Committee on Mineral Aggregates.

Impact Test

The resistance of stones to impact was determined according to ASTM D 3-18-58. Test values are empirical and indicate the distance in centimeters through which a 2-kg hammer falls to cause failure of the specimens (4).

Specific Gravity

Bulk and apparent specific gravities were determined in accordance with ASTM C 127.

Chemical Analyses

Chemical analyses were conducted according to ASTM C 25-58 to find CaO, MgO, SiO_2, Al_2O_3, Fe_2O_3, SO_3, R_2O_3, and loss on ignition.

TEST RESULTS

The test results reported by the Building Research Centre are given in Tables 1 and 2 (3).

Regardless of its location, Iraqi limestone shows a hyperbolic relation between the abrasion wear obtained in Los Angeles abrasion test and the crushing compressive strength. As the compressive strength increases, the percentage of wear decreases (Fig. 2). The relation could be explained since both tests indicate rock hardness. Figure 2b shows that the reciprocal of the abrasion wear and the compressive strength has a linear relation. The least squares method of analysis (5) was used for the linear equation

$$y = a + bx$$

where

$$b = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n} (x_i - \bar{x})^2}$$

and $a = \bar{y} - b\bar{x}$, to obtain Eq. 1.

$$\frac{10^4}{W} = 22.6 + 1.134\sigma \tag{1}$$

where W is the percentage of abrasion wear and σ is compressive strength in kg/cm^2. The correlation coefficient r was found to be 0.91 (r = 1 indicates perfect correlation, and r = 0 indicates no correlation). The expression for r is

$$r = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2 \sum_{i=1}^{n} (y_i - \bar{y})^2}}$$

If 1/W represents the y-axis, then, for regression with respect to y, the standard error of estimate (6) is equal to 0.0055 as given in Table 3.

Figure 1. Location of limestone in Iraq.

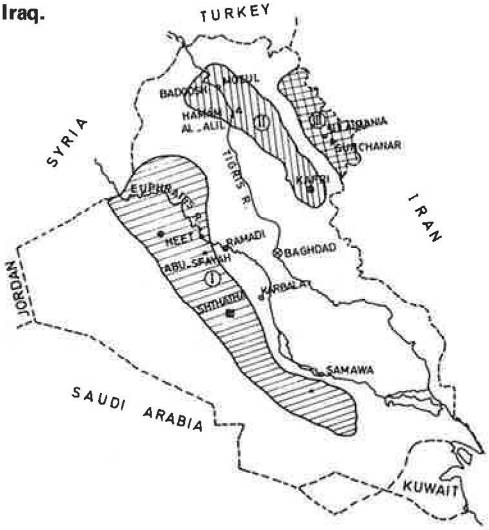


Table 1. Physical properties of limestone.

Sample	Area	Location	Specific Gravity Bulk	Specific Gravity Apparent	Absorption (percent)	W (percent)	1/W	Compressive Strength (kg/cm²)	Impact (cm)
1	Ramadi	Abu-Sfayyah-1	1.84	1.93	2.75	43.9	0.0228	144	10
2		Abu-Sfayyah-2	2.05	2.12	1.54	46.7	0.0214	125	6
3		Heet	2.07	2.16	1.99	—[a]	—[a]	168	5
4	Karbala	Kalat Mazloom-1	1.76	2.18	10.92	54.6	0.0183	114	4
5		Kalat Mazloom-2	1.77	2.08	8.27	82.0	0.0122	92	2
6		Kalat Mazloom-3	1.65	2.08	9.89	76.9	0.0130	125	3
7		Shthatha-1	—[b]	—[b]	—[b]	97.3	0.0103	85	4
8		Shthatha-2	1.15	1.55	22.63	92.6	0.0108	86	3
9		Shthatha-3	1.55	1.95	13.15	96.5	0.0104	85	3
10	Sulaimania	Surchanar-1	2.25	2.40	2.81	16.4	0.0610	396	10
11		Surchanar-2	2.17	2.36	3.58	23.1	0.0433	319	9
12		Surchanar-3	2.11	2.37	3.60	26.9	0.0371	333	10
13	Mosul	Badoosh-1	2.25	2.37	2.25	38.0	0.0263	210	9
14		Badoosh-2	2.05	2.04	1.87	33.1	0.0302	209	8
15		Badoosh-3	1.95	2.19	5.62	42.0	0.0238	190	10
16		Hammam Alil-1	2.56	2.58	0.47	43.2	0.0232	272	9
17		Hammam Alil-2	2.46	2.54	1.29	24.8	0.0403	372	12
18		Hammam Alil-3	2.34	2.44	1.73	32.1	0.0311	343	11

[a]Asphaltic mat. [b]Disintegrated.

Table 2. Chemical analyses of limestone.

Sample	Area	Location	Loss on Ignition	SiO_2	R_2O_3	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3
1	Ramadi	Abu-Sfayyah-1	42.29	0.80	1.41	0.28	1.13	54.90	0.14	0.36
2		Abu-Sfayyah-2	42.00	0.78	1.48	0.48	0.10	55.07	0.15	0.30
3		Heet	43.66	2.64	1.18	0.62	0.56	47.07	0.34	2.30
4	Karbala	Kalat Mazloom-1	43.72	2.06	2.61	1.10	1.56	47.55	1.27	0.58
5		Kalat Mazloom-2	42.14	1.48	1.03	0.25	0.74	54.10	0.89	0.34
6		Kalat Mazloom-3	40.65	0.69	0.86	0.02	0.70	52.52	2.32	0.58
7		Shthatha-1	42.02	0.66	1.12	0.64	0.47	55.01	0.86	0.30
8		Shthatha-2	42.60	1.68	0.50	0.27	0.27	54.00	0.69	0.30
9		Shthatha-3	43.21	1.04	0.43	0.27	0.16	54.16	0.57	0.52
10	Sulaimania	Surchanar-1	37.26	12.02	1.84	0.83	0.96	47.76	0.54	0.45
11		Surchanar-2	35.00	18.82	2.18	1.04	1.12	43.12	0.46	0.32
12		Surchanar-3	33.64	17.02	2.13	0.99	1.14	44.18	0.33	0.30
13	Mosul	Badoosh-1	42.70	1.63	1.12	0.50	0.62	53.10	1.07	0.21
14		Badoosh-2	39.50	8.06	4.53	2.18	2.25	47.04	0.46	0.28
15		Badoosh-3	39.90	6.45	3.14	1.49	1.68	49.43	0.72	0.30
16		Hammam Alil-1	40.00	4.33	2.42	1.16	1.26	51.74	0.74	0.43
17		Hammam Alil-2	43.50	1.88	3.22	0.45	0.72	50.58	1.93	0.37
18		Hammam Alil-3	44.32	1.32	1.20	0.58	0.62	50.51	1.86	0.41

A plot of abrasion wear versus impact values (Fig. 3a) shows that, as wear decreases, the impact value increases. The reciprocal of the percentage of wear gives a linear relation. The impact value is represented by Eq. 2 and is shown in Figure 3b.

$$\frac{10^4}{W} = 29.07 + 31.39\ I \tag{2}$$

where I is the impact value, in cm. The correlation coefficient for Figure 3b was found to be 0.76. The standard error of estimate with respect to the y-axis is 0.0090. Although Los Angeles abrasion and impact tests are empirical, both tests indicate rock toughness. Wear appears to result from both impact and surface abrasion; impact causes more loss (4). That could explain the relations shown in Figure 3.

A linear relation exists between bulk and apparent specific gravities of Iraqi limestone as shown in Figure 4. The relation, expressed by Eq. 3, has a correlation coefficient of 0.93.

$$G_b = 1.28\ G_a - 0.81 \tag{3}$$

The standard error of estimate with respect to the y-axis is 0.055.

The relation between percentage of wear and specific gravity is shown in Figure 5. The band between the dashed lines indicates that the scattering of points tends toward linear relations. The solid line halfway between the dashed lines uses the least squares method of analysis; thus, Eqs. 4 and 5 are obtained.

$$W = 202 - 70\ G_a \tag{4}$$

$$W = 162 - 57\ G_b \tag{5}$$

Figure 5 compares reasonably well with Figure 4. The scattering of points in Figure 5 seems to be reasonably acceptable for practical estimations; correlation coefficients are 0.74 and 0.83 respectively.

Figures 2a, 3b, 4, and 5 are combined to obtain the nomograph shown in Figure 6. Once the specific gravity of limestone is known, the nomograph can be used to estimate the compressive strength, the impact value, and the abrasion wear in the Los Angeles abrasion test. If the abrasion wear is known, the nomograph can also be used to estimate the other properties. The equations presented relate abrasion wear to other physical properties because the Los Angeles abrasion test is characterized by the quickness with which a sample may be tested and the applicability of the method to all types of aggregate.

Figure 7 shows that there seems to be a relation between SiO_2 content and abrasion wear. The wear increases as the SiO_2 content decreases. That is to be expected because SiO_2 is regarded as a hard mineral compared with other minerals that constitute limestone.

No relation exists between MgO content and abrasion wear as shown in the scattered points on Figure 8.

Figure 9 shows that CaO content has a certain tendency toward a linear relation with abrasion wear; however, more data are required before a definite conclusion can be reached.

No significant relation seems to exist between abrasion wear and Al_2O_3, Fe_2O_3, R_2O_3, and SO_3 contents.

CONCLUSIONS

The following conclusions may be drawn from the tests on Iraqi limestone:

1. Relations exist between abrasion wear in the Los Angeles abrasion test and the following physical properties: compressive strength, impact value, and specific gravity;
2. Equations relating abrasion wear to compressive strength, impact value, and specific gravity were derived;

Figure 2. Abrasion wear and compressive strength.

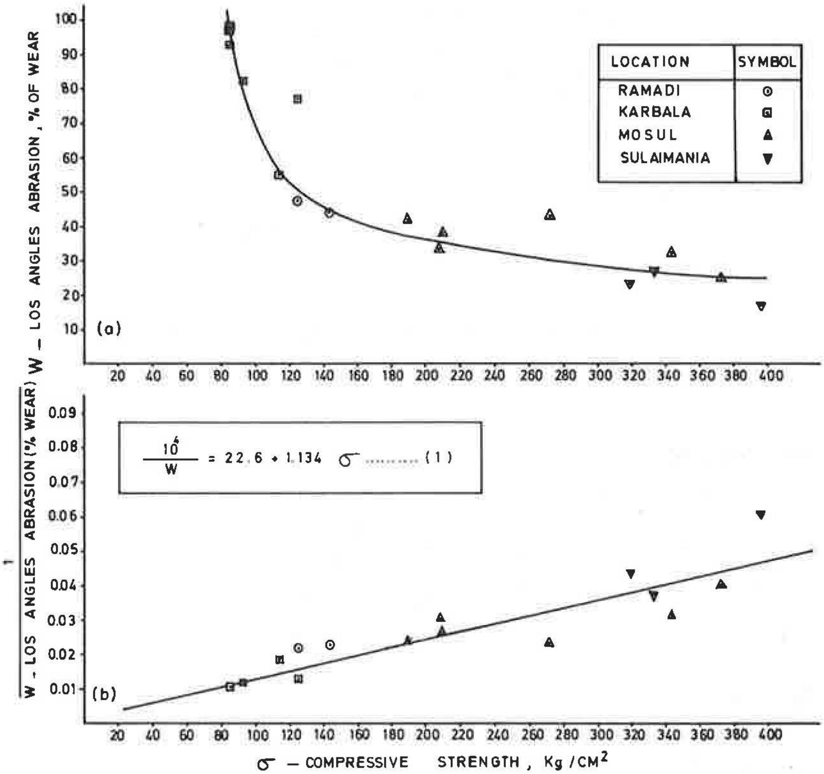


Table 3. Statistical analyses.

Figure	y	x	$\bar{y}$	$\bar{x}$	σ_y	σ_x	r	S_y
2a	1/W	σ	0.0256	205.8	0.0139	111.3	0.91	0.0055
3b	1/W	I	0.0256	7.24	0.0139	3.4	0.76	0.0090
4	G_b	G_a	2.00	2.20	0.26	0.35	0.93	0.055
5a	W	G_a	48.3	2.20	25	0.26	0.74	17
5b	W	G_b	48.3	2.00	25	0.36	0.83	14

Note: W = abraison wear, percent; σ = compressive strength, kg/cm^2; I = impact, cm; y, x = standard deviation with respect to y and x; r = correlation coefficient; and S_y = standard error of estimate with respect to y axis = $\sigma_y \sqrt{1 - r^2}$.

Figure 3. Abrasion wear and impact value.

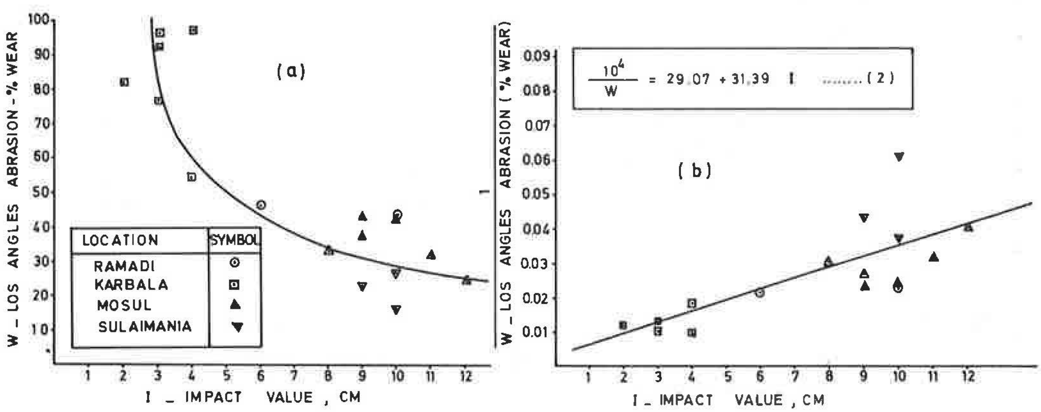


Figure 4. Bulk and apparent specific gravities.

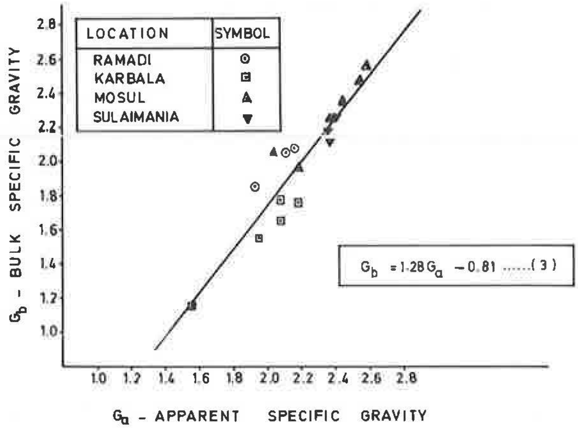


Figure 5. Abrasion wear and specific gravity.

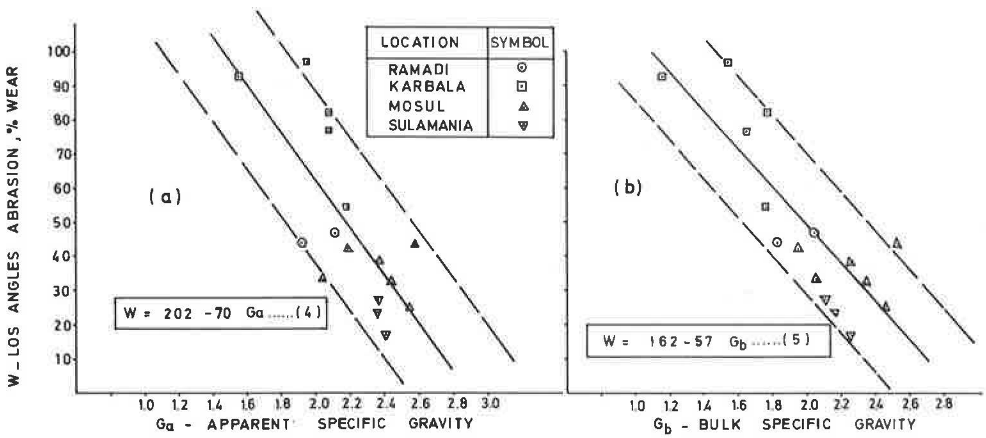


Figure 6. Correlation of physical properties.

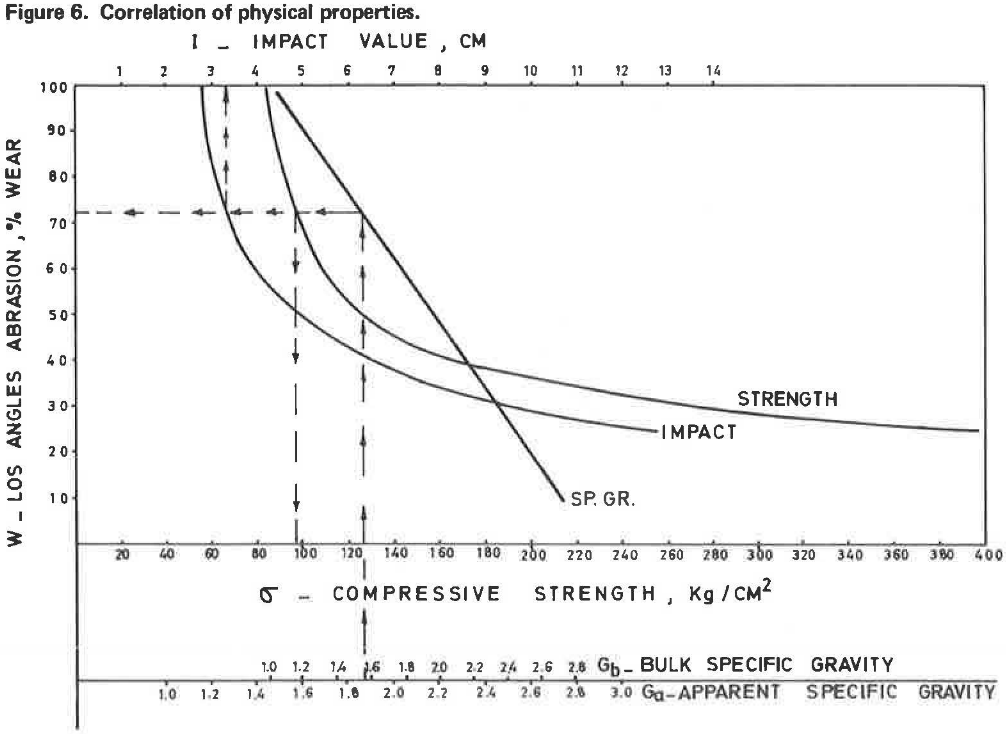


Figure 7. SiO_2 content and abrasion wear.

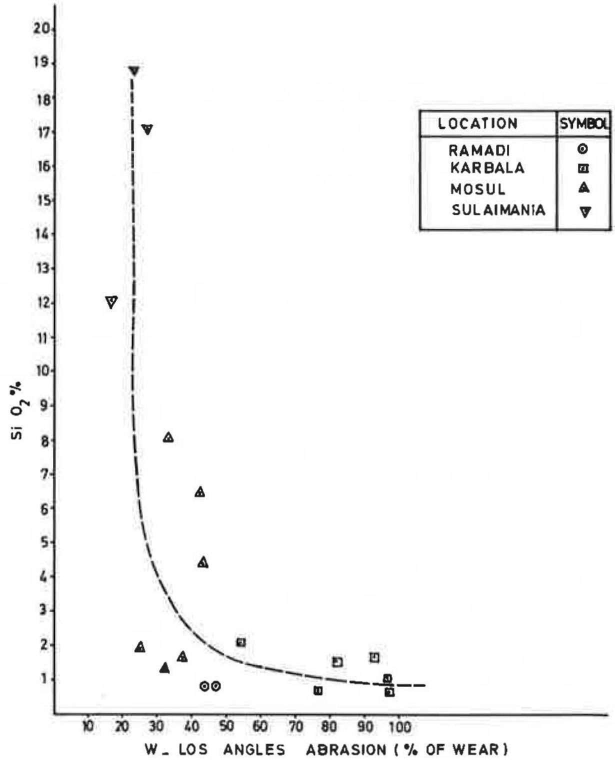


Figure 8. MgO content and abrasion wear.

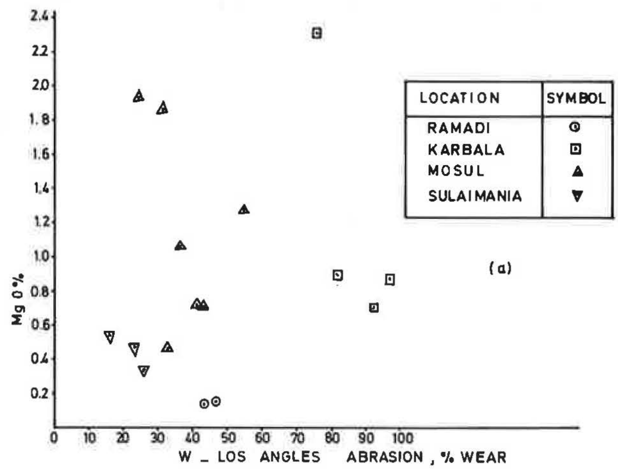
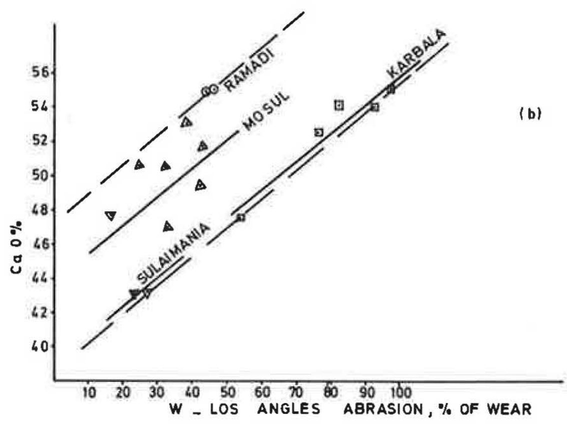


Figure 9. CaO content and abrasion wear.



3. A nomographic solution was presented that can be used to correlate the physical properties of Iraqi limestone and that will reduce the effort, tedious work, and time consumed in sample preparation and testing of limestone aggregates; and
4. SiO_2 and CaO contents influence the hardness and toughness of limestone.

RECOMMENDED RESEARCH

It is recommended that research be undertaken to investigate the applicability of the nomograph and equations presented to limestone from other regions; to expand the nomograph to include results of durability tests; and to investigate other gradations used in the Los Angeles abrasion test.

ACKNOWLEDGMENT

The author wishes to express his appreciation to the University of Baghdad for sponsoring this research.

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