Properties of Concrete Incorporating Natural and Crushed Stone Very Fine Sand

by Ahmed E. Ahmed and Ahmed A. El-Kourd

이 글은 매우 粒子가 작은모래(Very Fine Sand, VFS), 즉 75μm(No. 200)보다 더 粒子가 작은 모래를 콘크리트에 使用할 때 콘크리트性質의 研究資料이다.

우리나라는 自然河川骨材가 漸次的인 枯渴로 가까운 장래에는 必然的으로 海砂 및 碎骨材를 使用하게 될 것을 생각하여 일선에서 레미콘을 生産하시는 분들에게 다소 도움을 주고자 이글을 掲載합니다. 〈編輯者 註〉

EXPERIMENTAL DETAILS

Materials

Cement — Ordinary portland cement (ASTM Type I) was used.

Natural and crushed stone sands

Natural sand — The natural sand was obtained from Wadi Laban, a major quarrying area in Riyadh. The sand had been originally prepared at the crusher plant by combination of two equal volumes of sand sizes (0.0 to 2.0 mm and 0.0 to 5.0 mm). It was then washed in the laboratory over a No. 200 sieve to eliminate the very fine sand (VFS) content, and its gradation was modified to conform to the middle of the ASTM C 33 limits. When free of VFS, the sand was used for the preparation of the control mix. Table 1 gives the gradation of the sand and Table 2 shows its physical properties.

Crushed limestone sand — The crushed limestone sand was obtained from Wadi Al-Mahdiyah quarries in Riyadh. To modify its gradation to conform to the middle of the ASTM C 33 limits, the sand was washed in the laboratory over a No. 200 sieve, oven-dried and then separated into two size fractions (0.15 to 5 mm and 0.075 to 2.00 mm). The two fractions were then recombined in the proportions of 55 percent from the coarser fraction to 45 percent from the finer one to give a crushed stone sand free from VFS. The grading of the sand is given in Table 1 and its physical characteristics are given in Table 2.

Natural and crushed stone VFS — VFS is the fraction of sand passing a No. 200 sieve. The natural VFS was obtained from natural, oven-dried, unwashed sand by sieving over a No. 200 sieve.

The crushed limestone VFS was obtained by separating the limestone dust from dry crushed limestone sand using a vacuum filter from an asphalt mixing plant in Wadi Al-Mahdiyah. Table 3 shows the chemical composition of both types of VFS.

Table 1 — Grading of fine aggregates

Sieve size	Natural sand, percentage passing		Crushed stone sand, percentage passing	
	Washed	ASTM C 33	Washed	ASTM C 33
4.75 mm (#4)	100	95 - 100	100	95 - 100
2.36 mm (#8)	91	80 - 100	88	80 - 100
1.18 mm (#16)	72	50 - 85	70	50 - 85
600 μm (#30)	43	25 - 60	41	25 - 60
300 μm (#50)	18	10 - 30	21	10 - 30
150 μm (#100)	7	2 - 10	7	2 - 15
75 μm (#200)	0	0 - 5	0	0 - 7

Table 2 — Physical characteristics of aggregates

Property	Fine aggregates		Coarse aggregate
	Natural sand	Crushed stone sand	
Specific surface cm^2/gm	62	105.5	—
Specific gravity (S.S.D.)	2.62	2.50	2.62
Absorption, percent	1.83	1.17	1.90
Unit weight, kg/m^3	1630	1760	1495

1 cm^2/gm = 70.37 $in.^2/lb$; 1 kg/m^3 = 0.062 lb/ft^3.

Table 3 — Chemical analysis of very fine sand (VFS)

Constituent	Weight, percent	
	Natural VFS	Crushed stone VFS
$CaCO_3$	61.90	93.40
$MgCO_3$	1.68	2.04
SiO_2	31.15	1.10
Al_2O_3	3.20	1.50
Fe_2O_3	1.30	0.85
Na_2O	0.17	0.06
K_2O	0.13	0.13

Table 4 — Grading of coarse aggregate

Sieve size	Percentage passing
19.0 mm (¾ in.)	100
12.5 mm (½ in.)	60
9.5 mm (⅜ in.)	37
4.75 mm (#4)	9

Coarse aggregate — The coarse aggregate was crushed limestone passing the 19.0 mm (¾ in.) sieve and obtained by combination of two size fractions (10 to 19 and 5 to 10 mm) in the ratio of 3:2, giving the desired grading. The aggregate was laboratory-washed and oven-dried. The physical characteristics of the aggregate are given in Table 2 and the grading of the coarse aggregates are given in Table 4.

Concrete mixes — Two series of concrete mixtures were cast using natural and crushed stone sands. Series A was comprised of mixtures having an average slump of 100 ± 15 mm (4 + 0.5 in.); Series B encompassed mixtures having a constant water-cement ratio (w/c) of 0.7. Concrete mixtures made using natural sand incorporated 3, 5, 7, 10, and 15 percent of natural VFS by weight of fine aggregate, whereas mixtures made using crushed stone sand incorporated from 3 to 20 percent of limestone dust. The VFS was incorporated in the mixes as a direct replacement of an equivalent weight of sand. A control mix without VFS was included in each series. The mix proportions are given in Table 5.

Test specimens

The test specimens cast from each batch of Series A were 150-mm (6-in.) cubes for compressive strength testing and 150 x 150 x 500-mm (6 x 6 x 20-in.) prisms for flexural strength testing. Prisms of 50 x 50 x 285 mm (2 x 2 x 11.5 in.) were also cast for shrinkage measurements. In addition, 150-mm (6-in.) cubes were cast with steel bars with 12 and 16 mm cross sections (No. 4 and 5) embedded vertically at their centers for bond strength testing. From each of the 13 batches of Series B, six 150-mm cubes were cast for compressive strength testing.

The cast specimens were covered with wet burlap and left in the casting room for 24 hr. They were then demolded and cured continuously in a curing tank containing lime-saturated water at a temperature of 23 ± 2 C (73.4 ± 3.6 F) until testing. The drying shrinkage prisms were water-cured for 3 days and then air-cured at a temperature of 23 ± 2 C (73.4 ± 3.6 F) and 45 ± 5 percent relative humidity.

TEST RESULTS

The physical properties of fresh concrete are sum-

Table 5 — Mix proportions in 1-m cube of concrete

Mix series	Replacement of sand by VFS, percent	Natural sand concrete			Crushed stone sand concrete		
		Mixing water, kg	VFS, kg	Fine aggregate, kg	Mixing water, kg	VFS, kg	Fine aggregate, kg
A	0	227.5	0	720.0	224.0	0	720.0
	3	231.0	21.6	698.4	224.0	21.6	698.4
	5	234.5	36.0	684.0	227.5	36.0	684.0
	7	241.5	50.4	669.6	234.5	50.4	669.6
	10	259.0	72.0	648.0	234.5	72.0	648.0
	15	276.5	108.0	612.0	241.5	108.0	612.0
	20	—	—	—	259.0	144.0	576.0
B	0	245.0	0	720.0	245.0	0	720.0
	3	245.0	21.6	698.4	245.0	21.6	598.4
	5	245.0	36.0	684.0	245.0	36.0	584.0
	7	245.0	50.4	669.6	245.0	50.4	669.6
	10	245.0	72.0	684.6	245.0	72.0	648.0
	15	245.0	108.0	612.0	245.0	108.0	612.0
	20	—	—	—	245.0	144.0	576.0

Cement content in all mixes = 350 kg/m³ (590 lb/yd³).
Coarse aggregate content in all mixes = 1070 kg/m³ (1803 lb/yd³).
Slump of Series A = 100 ± 15 mm (4.0 ± 0.5 in.).
Total number of mixes = 26.
1 kg = 2.20 lb; 1 m³ = 1.307 yd³.

Table 6 — Properties of fresh natural and crushed stone sand concretes, Series A

Type of concrete	Replacement of sand by VFS, percent (by wt.)	w/c (by wt.)	Properties of fresh concrete: Slump, mm	Unit weight, kg/m³	Air content, percent	Bleeding water, percent
Natural sand concrete	0	0.65	100	2353	1.5	1.91
	3	0.66	110	2346	1.8	1.80
	5	0.67	100	2342	1.9	1.90
	7	0.69	95	2337	1.6	1.63
	10	0.74	100	2332	1.6	1.42
	15	0.79	100	2325	1.6	1.01
Crushed stone sand concrete	0	0.64	97	2377	1.6	2.86
	3	0.64	105	2351	2.5	2.43
	5	0.65	105	2337	2.8	2.80
	7	0.67	105	2326	2.8	2.10
	10	0.67	100	2326	2.9	1.80
	15	0.69	100	2328	2.4	1.46
	20	0.74	105	2330	1.7	0.50

1 mm = 0.04 in.; 1 kg/m³ = 0.062 lb/ft.³

Table 7 — Properties of fresh natural and crushed stone sand concretes, Series B

Type of concrete	Replacement of sand by VFS, percent (by wt.)	Mixing water, kg/m³	Properties of fresh concrete: Slump immediately after mixing, mm	Slump 5 min after mixing, mm	Unit weight, kg/m³
Natural sand concrete	0	245	145	120	2330
	3	245	120	75	2324
	5	245	120	75	2326
	7	245	90	65	2333
	10	245	85	55	2336
	15	245	60	38	2341
Crushed stone sand concrete	0	245	130	105	2336
	3	245	130	105	2323
	5	245	115	85	2363
	7	245	105	85	2364
	10	245	90	70	2334
	15	245	60	50	2343
	20	245	45	35	2375

1 kg/m³ = 0.062 lb/ft³; 1 mm = 0.04 in.

marized in Tables 6 and 7 and illustrated in Fig. 1 through 4. The compressive strengths are summarized in Table 8 and shown in Fig. 5 through 7. The flexural strength, bond strength, and drying shrinkage test results are shown in Fig. 8 through 11 and Table 9.

DISCUSSION OF RESULTS

Properties of fresh concrete

The influence of the VFS content on the *w/c* required to maintain a constant slump is shown in Fig. 1. It indicated clearly that the mixing water required increased with increasing VFS content. The *w/c* required at 10 percent crushed stone VFS content is the same as that needed at about 5 percent natural VFS content. Moreover, the amount of water required for natural sand mixes was higher than that for crushed stone sand mixes of similar VFS content. This is mainly

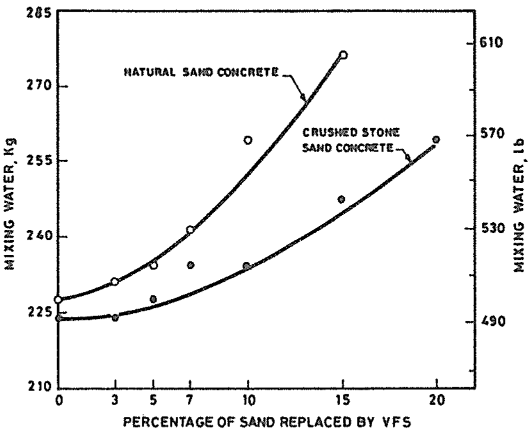

Fig. 1—Mixing water versus very fine sand (VFS) contents in natural and crushed sand concretes at a constant slump of 100 mm (4 in.)

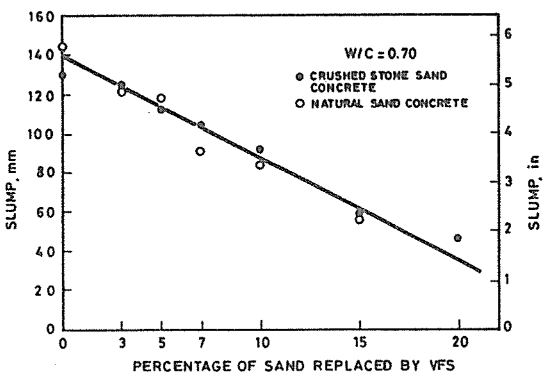

Fig. 2—Variation of slump (measured immediately after mixing) with VFS contents for concretes with w/c of 0.70

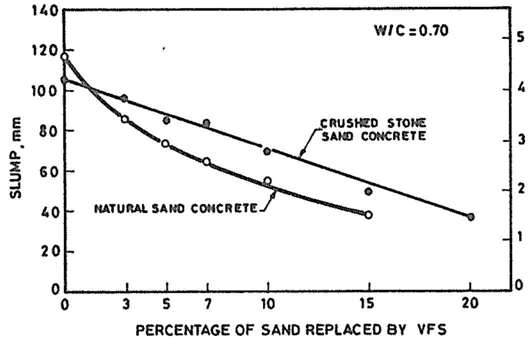

Fig. 3—Variation of slump (measured 5 min after mixing) with VFS contents of concretes with w/c of 0.70

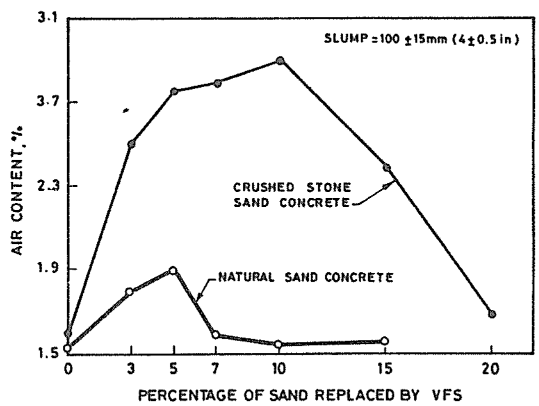

Fig. 4—Air contents versus VFS contents in natural and crushed stone sand concretes at a constant slump of 100 mm (4 in.)

attributed to the higher absorption and larger surface area of the natural sand incorporating relatively larger amounts of clay minerals (Table 4). It is worth mentioning that although the limestone dust incorporated in the crush stone sand has a larger surface area as compared to the natural VFS, the crushed stone sand has an overall relatively coarser grading.

Fig. 2 shows the variation of slump immediately measured after mixing with the VFS content in Series B mixes at a constant *w/c* of 0.70. A similar linear relationship appears to exist between both natural and crushed stone VFS and the slump. Due to the higher rate of absorption of the natural sand, the slump measured 5 minutes after mixing, however, showed relatively lower values compared to that of the crushed stone sand concrete (Fig. 3). The air content of crushed stone sand concrete was higher than that of natural sand concrete of similar VFS contents (Fig. 4). This is probably due to the angular and elongated particle shape of crushed stone sands as compared to the rounded and spherical natural sand. The air voids began to decrease with an increase of the natural VFS content beyond 5 percent and after a 10 percent increase in crushed stone VFS. A beneficial effect of increasing VFS was indicated by the reduction in bleeding (Table 6). Another added advantage was the observed increase in the cohesion of the mix.

Properties of hardened concrete compressive strength

Table 8 shows that the compressive strength of concrete mixes having the same consistency decreased with

Table 8 — Summary of compression strength test results

Mix series	Replacement of sand by VFS, percent	Natural sand concrete w/c (by wt.)	Natural sand concrete Compression strength, MPa 7-day	28-day	91-day	Crushed stone sand concrete w/c (by wt.)	Crushed stone sand concrete Compression strength, MPa 7-day	28-day	91-day
A	0	0.65	27.6	37.1	42.8	0.64	31.2	38.3	43.2
	3	0.66	25.8	35.7	49.9	0.64	28.7	36.9	40.3
	5	0.6,	23.3	33.3	36.6	0.65	26.2	36.3	39.1
	7	0.69	22.0	30.1	35.4	0.67	25.4	34.9	37.2
	10	0.74	20.5	27.5	34.5	0.67	26.9	35.5	38.8
	15	0.79	18.3	24.0	30.0	0.69	29.5	33.6	39.3
	20	—	—	—	—	0.74	28.6	31.2	35.7
B	0	0.70	—	30.0	—	0.70	—	30.3	—
	3	0.70	—	29.9	—	0.70	—	30.2	—
	5	0.70	—	29.8	—	0.70	—	31.8	—
	7	0.70	—	30.2	—	0.70	—	32.8	—
	10	0.70	—	31.1	—	0.70	—	32.0	—
	15	0.70	—	29.7	—	0.70	—	33.0	—
	20	—	—	—	—	0.70	—	34.7	—

1 MPa = 145 psi.

increasing percentage replacement of VFS. It can be seen in Fig. 7(a) that for increasing percentages of VFS replacement, the 28-day compressive strength of constant-slump concrete appears to decrease linearly. The compressive strength of crushed stone sand concrete at all ages was higher than that of natural sand concrete of similar VFS content. This is clearly attributed to the relatively lower *w/c* of the former. Fig. 7(a) also indicates that the compressive strength of crushed stone sand concrete is relatively less sensitive to variation in the VFS content as compared to that of natural sand concrete.

Fig. 7(b) shows that replacement of sand by VFS in natural sand concrete mixes having the same *w/c* did not affect their compressive strengths. In the case of crushed stone sand concrete, however, the strength showed a slight increase with increasing VFS content. Similar results have been reported by Malhotra and Carette,[6] who attributed the increase in the compressive strength of concrete incorporating limestone dust to the filler effect of the dust and the formation of carboaluminates.

Flexural strength

The variation of the 28-day flexural strength with the percentage replacement of VFS is illustrated in Fig. 8. It can be seen from the figure that the relationships between the VFS content and the 28-day flexural strength of Series A concretes are decrease linearly similarly to those observed for the compressive strength of the corresponding concretes.

Bond stress

Results of pullout tests on two bar sizes—16 and 12 mm cross sections (No. 4 and 5)—are shown in Fig. 9.

The general trend seen in Fig. 9 is that the bond stress of crushed stone sand concrete is higher than that of natural sand concretes having the same slump. Moreover, the bond stress is seen to be decreasing with increasing replacement of the VFS, with the crushed stone sand concrete being less sensitive to VFS content. This is due mainly to the relatively higher tensile strength of the crushed stone sand concrete and to the influence of the angular particle shape of the crushed stone sand. The 3 percent replacement is seen to be the optimum percentage that gave the highest bond stress in both natural and crushed stone sand concretes for the two bar sizes. This is unexplainable. Furthermore, in up to 20 percent replacement of crushed stone sand concrete, no noticeable decrease in the bond stress occurred. In natural sand concrete, however, a rapid decrease in the bond stress is clearly indicated beyond 5 percent replacement.

Drying shrinkage

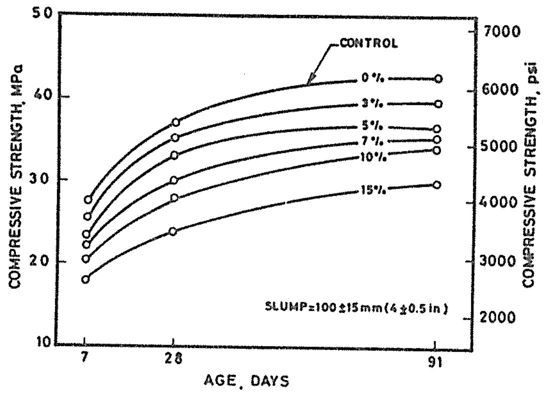

Fig. 5—Variation of compressive strength with age for natural sand concretes at a constant slump of 100 mm (4 in.)

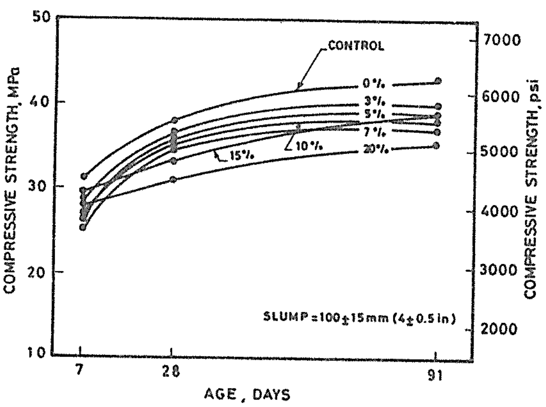

Fig. 6—Variation of compressive strength with age for crushed stone sand concretes at a constant slump of 100 mm (4 in.)

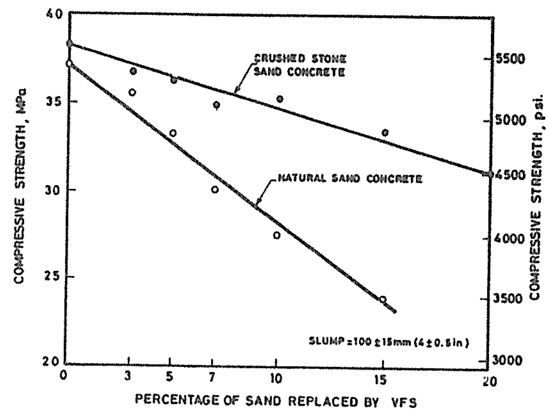

Fig. 7(a)—28-day compressive strength versus VFS concretes for concretes at a constant slump of 100 mm (4 in.)

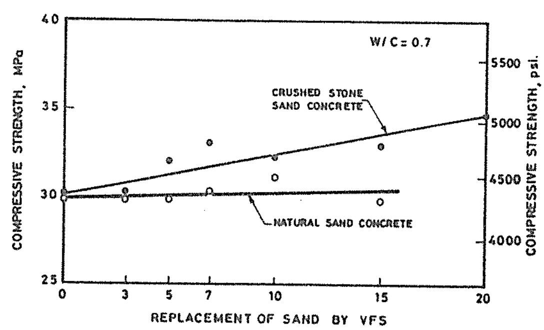

Fig. 7(b)—28-day compressive strength versus VFS contents for concretes at a constant w/c of 0.7

The drying shrinkage strains and water losses were monitored for a period of 330 days after an initial curing of 3 days in water. The results are shown in Fig. 10 and 11. In general, the drying shrinkage strains were found to increase with increasing replacement of VFS. Although the mixing water required for natural sand concrete was higher than that required for crushed stone sand concrete to attain the target slump, the drying shrinkage was almost the same at the identical percentage replacement of VFS. Moreover, the water loss was slightly higher in natural sand concrete. The increased shrinkage of the crushed limestone sand concrete may be due to the formation of carboaluminates[6] or to relatively higher carbonation shrinkage that added to the drying shrinkage.[10]

CONCLUSIONS

1. For concretes incorporating VFS as a replacement for fine aggregate, the increase in the water demand to attain a target slump of 100 mm (4 in.) was 6.2 percent at 7 percent natural VFS replacement and 7.8 percent at 15 percent limestone dust replacement. At 15 percent replacement, the increase in water demand for natural VFS was 21.5 percent versus 7.8 percent for limestone dust.

2. For concretes tested at a constant *w/c* of 0.70, the slump decreased linearly with increasing percentage of VFS replacement. The slump measured immediately after mixing was the same for both crushed stone natural sand concretes; however, natural sand concrete showed lower values of slump when measured 5 min

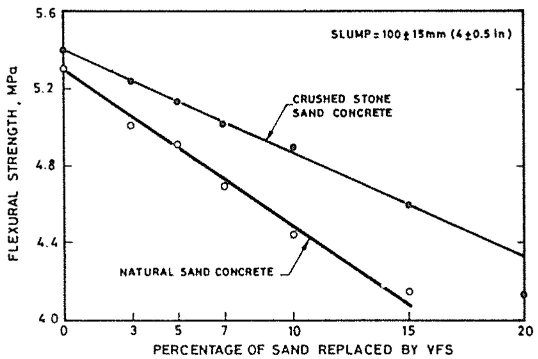

Fig. 8—28-day flexural strength versus VFS contents for concretes at a constant slump of 100 mm (1 MPa = 145 psi)

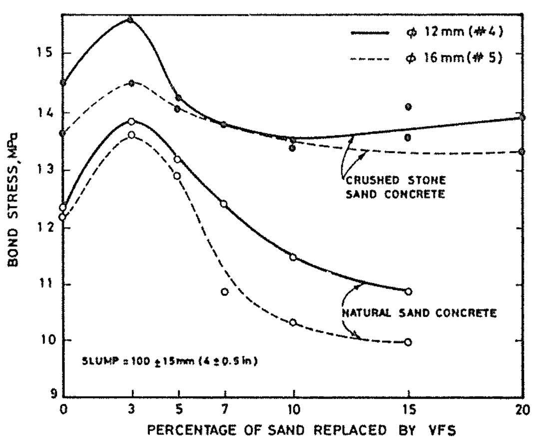

Fig. 9—Bond strength versus VFS contents in natural and crushed stone sand concretes at a constant slump of 100 mm (1 MPa = 145 psi)

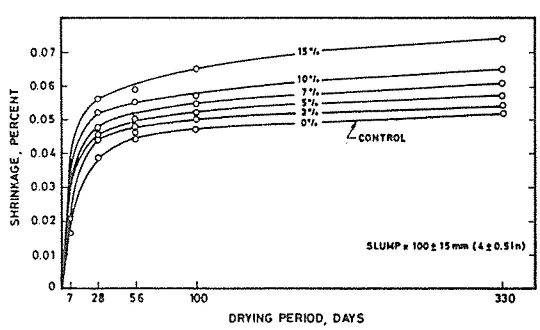

Fig. 10—Drying shrinkage strains versus age for natural sand concretes at a constant slump of 100 mm (4 in.)

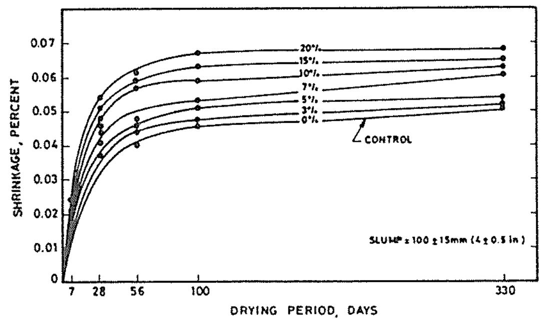

Fig. 11—Drying shrinkage strains versus age for crushed stone sand concretes at a constant slump of 100 mm (4 in.)

Table 9 — Summary of shrinkage test results

		Shrinkage measurement			
		Natural sand concrete		Crushed stone sand concrete	
Replacement of sand by VFS, percent	Period of drying, days	Drying shrinkage, percent	Moisture loss, gm	Drying shrinkage, percent	Moisture loss, gm
0	330	0.052	98.9	0.051	82.9
3	330	0.054	98.7	0.052	95.3
5	330	0.057	105.3	0.054	97.6
7	330	0.061	104.8	0.061	94.9
10	330	0.065	109.9	0.063	95.8
15	330	0.074	117.0	0.065	97.2
20	330	—	—	0.068	100.5

1 gm = 0.0022 lb.

after mixing.

3. The nonentrained air content in crushed stone sand concrete was higher than that in natural sand concrete of the same slump, with optimum values at 10 and 5 percent replacement levels, respectively.

4. The compressive strength of concretes having constant slump decreased linearly with increasing percentage of VFS replacement. At 5 percent replacement, the strength of natural sand concrete was about 10 percent lower than that of the control mix, whereas similar strength loss was observed in crushed stone sand concretes at 12 percent replacement level. A similar trend was observed for the flexural strength.

5. The increase in percentage of VFS replacement did not much affect the ultimate bond stress of crushed stone sand concrete. The effect of increasing VFS replacement was much more pronounced in natural sand concrete, particularly beyond 5 percent replacement.

6. Drying shrinkage strains of natural and crushed stone sand concretes of constant slump increased with increasing VFS replacement. No difference was observed between shrinkage values of both concretes at a

constant replacement.

7. The limited test results of the study indicated that material finer than 75 μm may be limited to a maximum of 5 and 10 percent, respectively, in Riyadh natural and crushed stone sands used in concrete. When workability of concrete is improved by water reducers, increasing of these limits to 7 and 15 percent, respectively, may not significantly affect the air content, compressive strength, and bond stress of concrete and therefore may be acceptable.

REFERENCES

1. Atta, A. H., and Mansouri, A. H., "Study of the Properties of Riyadh Sands Used in Mortar and Concrete," *Journal of Engineering Sciences* (Riyadh), V. 9, No. 1, 1983, pp. 1-20.

2. Siddiqi, G. H.; Ahmed, A. E.; Unver, M. B.; and Mushrif, M. A., "Effect of Riyadh Sand on Performance of Concrete," *Research Report* No. 14/1404, College of Engineering, KSU, Riyadh, 1986, 66 pp.

3. Neville, A. M., *Properties of Concrete*, 2nd Edition, Pitman Publishing Limited, London, 1978, p. 133.

4. Haque, M. N., "Some Effects of Silt Contents on the Strength of All-in-Aggregate Concrete," *Cement and Concrete Research*, V. 10, No. 1, Jan. 1980, pp. 13-22.

5. Ghosh, R. K.; Sethi, K. K.; and Parkashi, V., "Suitability of Manufactured Sand for Making Quality Concrete," *Journal of the Indian Roads Congress* (New Delhi), V. 33, No. 2, Sept. 1970, pp. 337-357.

6. Malhotra, V. M., and Carette, G. G., "Performance of Concrete Incorporating Limestone Dust as Partial Replacement for Sand," ACI JOURNAL, *Proceedings* V. 82, No. 3, May-June 1985, pp. 363-371.

7. Popovics, Sandor, *Concrete-Making Materials*, Hemisphere Publishing Corp., Washington, D.C., 1979, pp. 207-221.

8. Troxell, George E.; Davis, Harmer E.; and Kelly, Joe W., *Composition and Properties of Concrete*, 2nd Edition, McGraw-Hill Book Co., New York, 1968, p. 88.

9. Haque, M. N., "No-Slump Concrete with Fine Sand and Clay," *Cement and Concrete Research*, V. 11, No. 4, July 1981, pp. 531-539.

10. Mindess, Sydney, and Young, J. Francis, *Concrete*, Prentice-Hall, Inc., Englewood Cliffs, 1981, p. 498.

광고 안내

당 협회는 레미콘지를 계간으로 발간하여 그동안 레미콘업계뿐만 아니라 학계, 정부기관 각종 기업체의 성원으로 광범위한 독자층을 형성하고 있읍니다.

당 협회는 레미콘지에 다음과 같이 표지면을 광고란으로 할애하여 관련업체의 광고, 홍보를 게제하고 있으니 귀사의 적극 이용을 바랍니다.

— 다 음 —

게 제 면	색 도	광 고 료	크 기
표지 2면	칼 라	50만원(부가세 별도)	전 면
표지 3면	칼 라	40만원(부가세 별도)	전 면
표지 4면	칼 라	60만원(부가세 별도)	전 면

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