Dirty Aggregate, What Difference Does It Make?

EUGENE BUTH, DON L. IVEY and TEDDY J. HIRSCH, Texas Transportation Institute, Texas A&M University

The effects of clay in concrete fine aggregate on the properties of concrete are presented and discussed. The two most generally used tests, the loss by decantation and sand equivalent tests, are examined. The ability of these tests to measure the observed effects of the clay fraction of an aggregate on the properties of concrete is illustrated.

The concrete properties under study were water requirement, strength, shrinkage and freeze-thaw durability. Both the quantity and activity of the clay fraction were found to be influential. Increases in quantity and activity of clay cause increases in water requirement and shrinkage and decreases in strength and durability. Because of the influence of the activity of the clay fraction, the sand equivalent test is the better indicator of the effect on concrete of the clay fraction of an aggregate.

•SPECIFICATIONS for concrete aggregates represent a compromise between the desire for a perfect material and the necessity for using materials that are economically available. In many instances, the engineer is faced with the problem of writing a specification to limit a certain property and finds that sufficient information concerning that property, or how to measure it, is not available. These encounters have resulted in the use of phrases such as "harmful amounts," "excessive amounts," or in the assignment of some arbitrary quantitative measures which have been adjusted first in one direction then in another, resulting in a loss of confidence in some specifications. One of the examples of this type of specification is in the area of cleanliness of concrete aggregates.

Before the development of the sand equivalent test, the criteria to control the clay and silt size fractions of concrete aggregates were based strictly on the amount of these fractions, without regard to other properties. Even if these other properties were generally the same for different aggregates, sufficient information was not available to define quantitatively the effects of this fraction on the properties of concrete.

This study was undertaken to determine the factors of the minus No. 200 mesh fraction influencing concrete properties and to determine quantitatively the effect of these factors on concrete properties.

EXPERIMENTAL PROGRAM

Two types of coarse aggregate were used in the concretes, a high-quality "clean" siliceous aggregate and a high-quality "clean" crushed limestone. A single high-quality siliceous fine aggregate was used in all concrete mixes. Both coarse and fine aggregates were washed with a detergent to remove all minus No. 200 mesh material. The desired amount and type of clay was then added to the fine aggregate at the time of mixing. The volumes of coarse aggregate and cement were held constant, and "clean" sand was adjusted so that the volume of sand plus clay fraction varied only with variation in water. The specified amounts of dry materials were used in each batch and the water was regulated to control the slump. Specimens were molded for the determination of strength, shrinkage and freeze-thaw resistance. In total, 64 batches of concrete were tested.

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Initially, two groups of concrete batches (Series A and B) were tested to determine the significance of the influence of the amount and activity of the minus No. 200 mesh fraction. (The activity of the clay is defined as its ability to attract an absorbed film of water; in this work, the liquid limit value (AASHO T 80-60) was chosen as an indicator of this activity.) The aggregates contained from 0 to 2¼ percent minus No. 200 mesh material with liquid limits ranging from 0 to 640 percent. Significant variations in the concrete properties were indicated. Two additional groups of batches (Series C and E) were then tested to substantiate the rough trends developed by Series A and B.

Physical properties of the aggregates used in Series A, B, C, and E tests are given in Table 1.

MIX DATA AND PROPERTIES OF CONCRETE

The concrete mix data and concrete properties for A and B Series are given in Tables 2 and 3. Similar information for the C Series is given in Tables 4 and 5. Table 6 gives the concrete mix data and compressive strengths for the E Series.

RESULTS AND DISCUSSION

Aggregate Tests

The fact that minus No. 200 mesh size particles in concrete aggregates are considered deleterious is reflected in almost all specifications. Usually, limits have been placed on the amount of this size material. Before the development of the sand equivalent test, little effort had been devoted to distinguishing between active and inert minus No. 200 mesh particles.

The sand equivalent test procedure (AASHO T 176-56) uses a graduated plastic cylinder and a solution of glycerin and calcium chloride to separate the clay and sand fractions. The sample and solution are placed inside the cylinder and a vigorous shaking action is imparted to the apparatus. An agitator tube is used to flush the clay size particles up in the solution. After a prescribed settling period, the height of the sand and the total height of sand plus clay are read. The ratio of the sand height to total height, expressed as a percentage, is the sand equivalent value (Table 7). The activity of the clay results in a magnification in volume of the clay fraction which decreases the sand equivalent value (1).

The loss by decantation procedure (Texas Method Tex-406-A) uses a pycnometer and water to separate the clay and sand fraction. A mild washing action is used and the clay size fraction is decanted over a No. 200 mesh sieve. Material retained on the sieve is returned to the sample. The loss is expressed on a weight basis and reflects only the amount of material decanted.

Variations in the liquid limit of the minus No. 200 mesh fraction of commercial concrete sands proved to be large enough to be of significance. The extremes in sand equivalent value for a 1 percent decantation loss were 77 and 91 (2).

TABLE 1
PHYSICAL PROPERTIES OF AGGREGATES

Item	A and B Series			C and E Series	
	Siliceous Coarse	Siliceous Fine	Crushed Limestone Coarse	Siliceous Coarse	Siliceous Fine
Unit weight, pcf (dry loose)	93.0	98.5	88.0	98.0	100.0
Specific gravity (SSD)	2.61	2.62	2.64	2.64	2.63
Absorption (% of dry wt.)	1.2	0.8	1.4	1.2	0.8
Sieve analysis, cumulative percent retained on					
¾ in.	0.0	–	0.0	0.0	–
½ in.	35.0	–	35.0	35.0	–
⅜ in.	60.0	–	60.0	60.0	–
No. 4	100.0	0.24	100.0	100.0	0.76
No. 8	–	10.10	–	–	15.20
No. 16	–	26.21	–	–	33.22
No. 30	–	41.21	–	–	54.28
No. 50	–	83.29	–	–	89.60
No. 100	–	98.62	–	–	98.42
No. 200	–	100.00	–	–	100.00

Plastic Concrete

The primary influence of clay on the plastic concrete was manifest in the amount of water required to maintain a given slump. The water-cement ratio for a 5-sack mixture with a 3-in. slump varied from an average of 0.56 to 0.78 by weight when the sand equivalent value changed from 100 to 30 (Fig. 1). However, the mixtures containing large amounts of highly plastic clay exhibited better workability and placeability than did the cleaner mixtures with the same slump.

TABLE 2

CONCRETE MIX DATA—A AND B SERIES

(Quantities per Cubic Yard of Concrete)

Batch	Aggregate		Type I Cement		Water (lb)	Minus 200 Mesh Fraction			Air (%)	Slump (in.)	Wet Unit Wt. (pcf)
	Coarse (lb)	Fine (lb)	Sacks	Pounds		Type*	Liquid Limit	% of Total Agg. Wt.			
A11	1840	1300	5.02	472	247	—	—	0.00	6.1	3½	143.0
A12	1810	1290	5.07	477	287	NC	35	0.74	5.0	3¼	144.3
A13	1960	1160	5.11	480	287	NC	35	1.46	4.5	3	146.0
A14	1960	1080	5.26	495	300	NC	35	2.36	4.1	3	145.0
A15	1820	1360	5.07	477	282	S	0	1.42	3.0	2¾	147.5
A16	1810	1280	5.05	475	273	S-M	35	1.48	4.9	2¾	144.0
A17	1780	1220	4.97	467	352	S-M	200	1.50	2.9	3¼	142.9
A18	1840	1100	5.11	480	386	S-M	400	1.57	3.0	3	142.9
A19	1700	1110	4.95	465	406	M	640	1.60	3.3	3	138.6
B11	1670	1490	4.97	467	287	—	—	0.00	4.1	3	145.0
B12	1680	1380	5.00	470	271	NC	35	0.74	6.0	3½	141.0
B13	1720	1380	5.11	480	289	NC	35	1.49	3.0	3	145.0
B14	1670	1330	4.97	467	334	NC	35	2.25	4.2	2¾	143.0
B15	1700	1400	5.05	475	296	L	0	1.48	3.1	3	145.5

*NC, natural clay; S, silica flour; S-M, silica-montmorillonite mixture; M, montmorillonite; L, limestone fines.

TABLE 3

CONCRETE PROPERTIES—A AND B SERIES

Batch	Dynamic Modulus of Elasticity (10^{-6} psi—ASTM C215)		Modulus of Rupture* (psi)		Compressive Strength (psi—ASTM C116)		Shrinkage** (μ-in./in.)	
	7 Day	28 Day	7 Day	28 Day	7 Day	28 Day	28 Day	120 Day
A11	5.86	6.25	810	780	3300	3670	235	435
A12	5.61	6.31	660	720	2690	3370	383	565
A13	5.79	5.99	640	580	2850	3220	353	490
A14	5.26	6.64	580	650	2390	3000	347	518
A15	6.40	6.46	880	770	2890	2920	265	420
A16	5.48	6.00	650	790	2750	3530	312	450
A17	4.81	5.16	510	560	2160	2520	373	630
A18	4.58	4.72	500	520	2370	2430	433	730
A19	3.96	4.33	410	450	1840	2290	465	768
B11	5.76	6.22	700	830	2900	3210	432	628
B12	5.44	5.64	580	760	2790	2640	370	560
B13	5.35	5.95	770	790	3570	3810	312	430
B14	5.14	5.38	600	730	2450	2750	440	665
B15	5.52	5.84	830	810	3120	3890	285	455

*Center point 3 by 4 by 16-in. prisms.

**ASTM C157 except specimens had 4 by 4-in. cross section and were internally vibrated; specimens were moist cured for 3 days then dried at 50 ±5 percent relative humidity and 72 ±2 F.

TABLE 4

CONCRETE MIX DATA—C SERIES

(Quantities per Cubic Yard of Concrete)

Batch	Aggregate		Type I Cement		Water (lb)	Minus 200 Mesh Fraction		Air (%)	Slump (in.)	Wet Unit Wt. (pcf)
	Coarse (lb)	Fine (lb)	Sacks	Pounds		Liquid Limit	% of Total Agg. Wt.			
C10	1770	1400	5.04	474	276	—	0.00	4.7	3	145.2
C11	1760	1350	4.99	469	297	0	1.59	5.3	3	145.6
C12	1800	1350	5.04	474	283	35	1.59	4.2	3	146.5
C13	1770	1290	4.98	468	224	70	1.61	4.4	3½	144.5
C14	1790	1270	4.99	469	321	0	3.24	5.2	3¼	144.8
C15	1790	1230	4.99	460	304	35	3.39	4.0	3½	144.0
C16	1790	1150	5.01	471	338	70	3.38	4.5	3	142.4
C17	1810	1080	5.05	475	359	0	5.55	5.2	3½	144.0
C18	1780	1140	4.97	467	319	35	5.43	4.8	3	142.8
C19	1800	1060	5.02	472	357	70	5.59	4.0	3	142.4

TABLE 5

CONCRETE PROPERTIES—C SERIES

Batch	Dynamic Modulus of Elasticity (10^{-6} psi—ASTM C215)			Modulus of Rupture (psi—ASTM C78)			Compressive Strength (psi—ASTM C39)			Shrinkage* (μ-in./in.)	
	7 Day	14 Day	28 Day	7 Day	14 Day	28 Day	7 Day	14 Day	28 Day	28 Day	120 Day
C10	6.21	6.45	6.54	620	630	660	4500	4730	4990	355	520
C11	5.60	6.49	6.78	680	695	685	4800	5230	5310	325	510
C12	5.82	6.46	6.73	635	675	670	4620	4900	5240	360	550
C13	5.89	5.99	6.26	550	625	650	4070	4310	4580	375	580
C14	6.02	5.49	6.31	585	585	540	3680	4210	4700	390	570
C15	6.02	6.08	6.26	590	615	635	3910	4150	4480	340	475
C16	5.38	5.39	5.63	535	460	465	3400	3810	3860	470	675
C17	6.03	6.27	6.35	590	585	620	3930	4340	4700	350	510
C18	5.46	5.46	5.61	525	490	520	3590	3820	4220	470	720
C19	5.36	5.55	5.77	540	515	530	3560	3950	4160	460	645

*ASTM C157 with specimens being moist cured for 7 days, then dried at 50 ±5 percent relative humidity and 72 ±2 F.

TABLE 6

CONCRETE MIX DATA AND COMPRESSIVE STRENGTHS—E SERIES

(Quantities per Cubic Yard of Concrete)

Batch	Aggregate		Cement		Water (lb)	Minus 200 Mesh Fraction*		Air (%)	Slump (in.)	Wet Unit Wt. (pcf)	Compressive Strength	
	Coarse (lb)	Fine (lb)	Pounds	Sacks		(lb)	% of Total Agg. Wt.				7 Day (psi)	28 Day (psi)
E10	1730	1370	455	4.84	244	0	0	8.5	4	140	3050	3570
E20	1800	1440	475	5.05	251	0	0	5.4	2	146	3590	4280
E30	1740	1430	458	4.87	255	0	0	5.2	$2^3/_4$	144	3260	3920
E11	1770	1360	466	4.96	304	12.6	0.4	5.5	$2^3/_4$	144	3440	4270
E21	1770	1360	466	4.96	253	12.6	0.4	6.2	$3^1/_4$	143	3150	4030
E31	1770	1360	466	4.96	268	12.6	0.4	6.0	$3^1/_2$	144	3520	4010
E12	1760	1330	463	4.93	282	36.3	1.2	5.4	$3^1/_4$	144	3240	3650
E22	1760	1330	463	4.93	277	36.3	1.2	5.9	$3^1/_2$	143	3190	3670
E32	1780	1340	469	4.99	272	36.8	1.2	5.9	$3^1/_4$	144	3480	3940
E13	1770	1310	466	4.96	278	60.4	1.9	5.1	3	144	3170	3700
E23	1770	1310	466	4.96	287	60.4	1.9	4.5	3	144	3040	3760
E33	1760	1300	463	4.93	273	60.0	1.9	6.1	3	143	3130	3320
E14	1770	1290	466	4.96	292	84.4	2.8	4.5	$3^1/_2$	144	3040	3720
E24	1770	1290	466	4.96	280	84.4	2.8	5.2	$3^1/_4$	144	3150	3360
E34	1760	1280	463	4.93	273	83.9	2.8	5.5	$3^1/_4$	143	3110	3400
E15	1760	1230	463	4.93	303	131.7	4.4	5.0	3	144	2750	3120
E25	1770	1200	466	4.96	315	132.3	4.4	4.5	$3^1/_2$	144	2540	3100
E35	1770	1200	466	4.96	299	132.3	4.4	5.0	$3^1/_4$	144	3020	3280
E16	1790	1080	472	5.02	321	194.9	6.8	4.5	$3^1/_2$	143	2550	2840
E26	1780	1070	469	4.99	326	193.7	6.8	5.5	$3^1/_4$	142	2320	2810
E36	1760	1060	463	4.93	322	191.4	6.8	5.2	$3^1/_4$	141	2280	2510
E17	1760	1010	463	4.93	350	250.6	9.0	4.4	$3^1/_4$	142	2100	2460
E27	1750	1010	460	4.89	348	248.9	9.0	5.1	$3^1/_4$	141	1900	2190
E37	1780	960	469	4.99	354	253.2	9.0	4.5	$3^1/_2$	142	1990	2220

*Liquid limit of minus 200 mesh fraction is 35 percent.

TABLE 7

CALCULATED SAND EQUIVALENT VALUES FOR AGGREGATES USED IN CONCRETE MIXES*

Batch	Sand Equiv. Value	Batch	Sand Equiv. Value
A11	100	C12	82
A12	90	C13	70
A13	80	C14	86
A14	70	C15	66
A15	94	C16	51
A16	81	C17	79
A17	49	C18	53
A18	30	C19	38
A19	22		
B11	100	E10, 20, 30	100
B12	91	E11, 21, 31	95
B13	82	E12, 22, 32	85
B14	75	E13, 23, 33	78
B15	94	E14, 24, 34	71
		E15, 25, 35	59
C10	100	E16, 26, 36	46
C11	94	E17, 27, 37	39

*Calculated by $SE = \frac{100}{1 + P\,(0.1318\,LL + 1.79)}$

This observation lends support to Tremper and Haskell's statement (3): "Instances are on record of the use of a soil as an admixture to concrete with evident improvement in workability and without serious effect on the compressive strength, particularly if the mix was lean and harsh."

It was also observed that the required quantity of air-entraining admixture for a given air content varied some 1,000 percent for the full range of sand equivalent values: from $5^1/_2$ oz/bag for a sand equivalent value of 39, down to $^1/_2$ oz/bag for a sand equivalent value of 100.

Strength of Concrete

The amount and type of minus No. 200 mesh material used in each batch strongly influenced the amount of water required to maintain a given slump. This created a significant variation in the water-cement ratio. With this in mind, the first and most obvious relationship is concrete strength and water-cement ratio (Fig. 2). Values of compressive strength for the mixes having water-cement ratios of 0.6 were used as the 100 percent value and the strengths are shown relative to this value. The correlation coefficient of 0.78 indicates the existence of a significant correlation. If variations in compressive strength are compared with the amount of minus No. 200 mesh material (liquid limit being held constant at 35 percent, the correlation coefficient is significantly improved (Fig. 3)). However, if the liquid limit is allowed to vary, this correlation breaks down due to strong influence of this parameter on concrete strength.

A very slight improvement on the correlation of strength with water-cement ratio was obtained by comparing the modulus of rupture and compressive strengths to the sand equivalent value. A correlation coefficient of 0.83 is obtained for each of these relationships (Figs. 4 and 5). The difference between the two correlation coefficients (0.78 for compressive strength vs water-cement ratio, 0.83 for compressive strength vs sand equivalent value) was tested and found not to be statistically significant. The possibility remains, however, that sand equivalent value reflects influential parameters

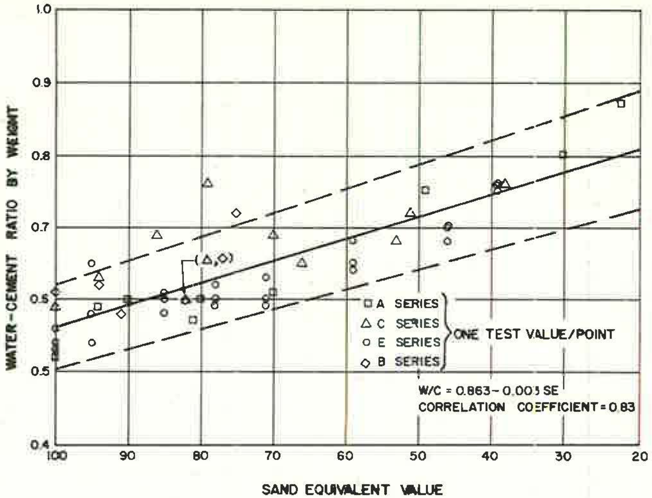


Figure 1. Effect of sand equivalent value on water-cement ratio for 5-sack mix with 3-in. slump.

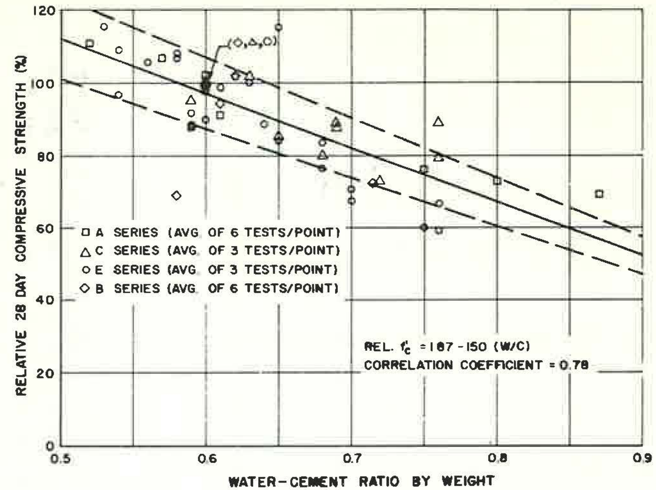


Figure 2. Relationship between 28-day compressive strength and water-cement ratio.

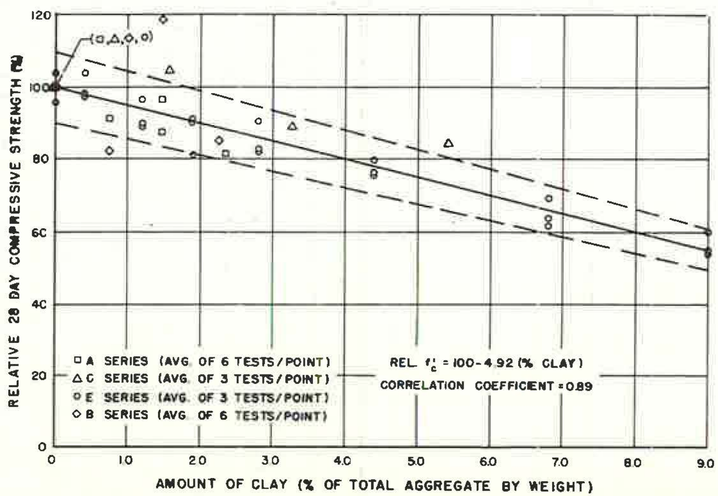


Figure 3. Influence of amount of clay fraction (LL = 35%) on 28-day compressive strength.

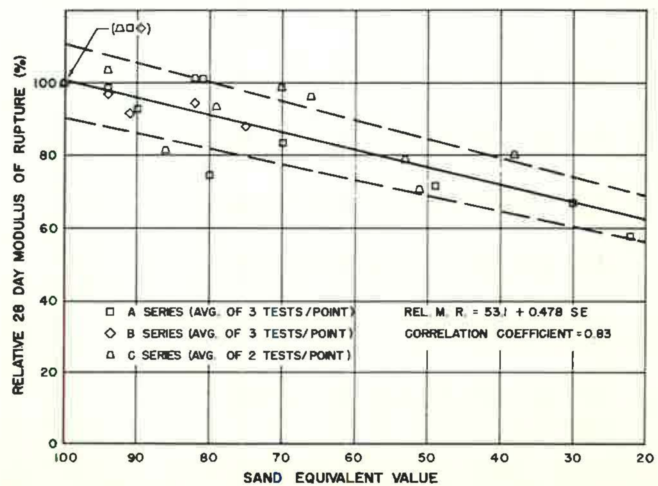


Figure 4. Relationship between 28-day modulus of rupture and sand equivalent value.

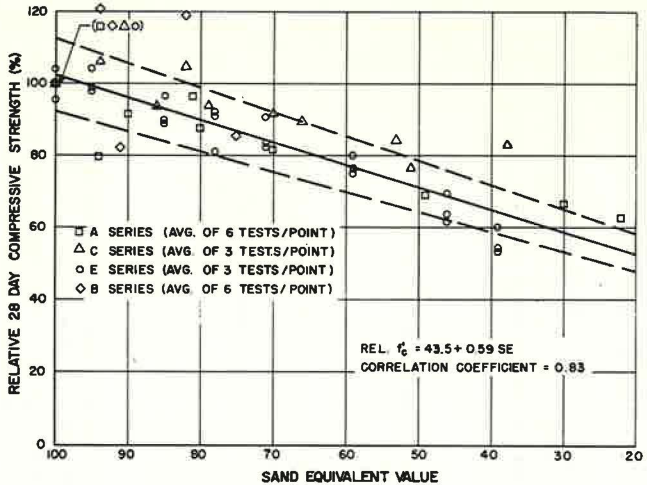


Figure 5. Variation in 28-day compressive strength with sand equivalent value.

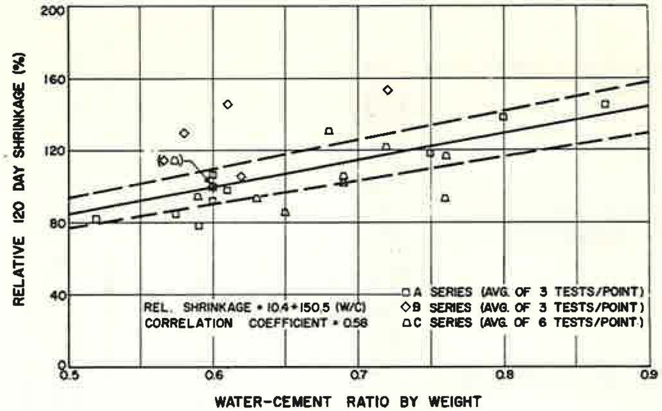


Figure 6. Relationship between 120-day shrinkage and water-cement ratio.

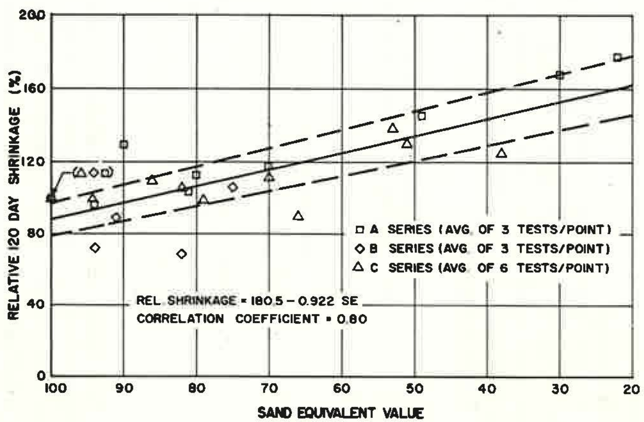


Figure 7. Relationship between 120-day shrinkage and sand equivalent value.

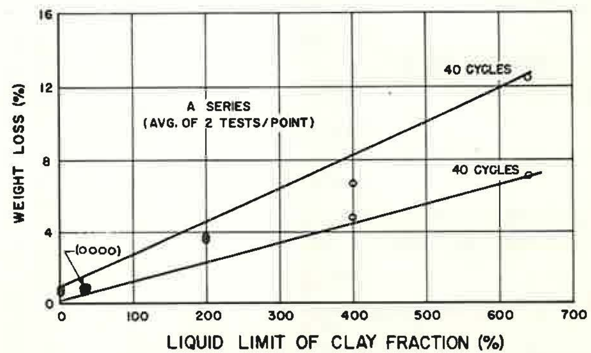
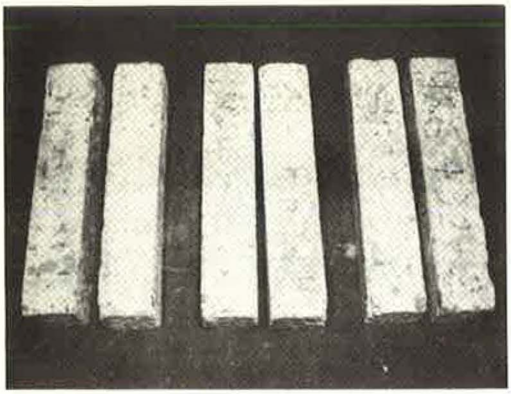


Figure 8. Relationship between weight loss of freeze-thaw specimens and LL of clay fraction after 300 cycles of ASTM C290.



A15	A16	A13	A17	A18	A19
1.42% Clay	1.48% Clay	1.48% Clay	1.50% Clay	1.57% Clay	1.60% Clay
0% LL	35% LL	35% LL	200% LL	400% LL	640% LL
SE = 94	SE = 81	SE = 80	SE = 49	SE = 30	SE = 22

Figure 9. Specimens from A Series batches after completion of freeze-thaw testing by ASTM C290.

other than the water requirement of the sand. One possible parameter is the difference in specific surface as it affects concrete strength. Another consideration might be differences in the load-resisting properties of active particles having adsorbed films of water as opposed to inactive particles that have comparatively little surface attraction for water molecules.

Shrinkage of Concrete

Shrinkage of the concretes studied correlates to some degree with water-cement ratio but to a higher degree with sand equivalent value (Figs. 6 and 7). In each case a decrease in sand equivalent value or an increase in water-cement ratio causes an increase in shrinkage.

Hveem and Tremper (4) reported a correlation coefficient of 0.66 between drying shrinkage of mortar (after 14 days of drying) and sand equivalent value of commercially produced concrete sands. However, when the absorption of the sand was included the correlation was significantly improved (correlation coefficient 0.83). Chamberlin (5, p. 32-33) reports:

> Interestingly, sand equivalents of the experimental aggregates also correlate with drying shrinkage and to a rather high degree.
>
> * * *
>
> The relative contribution of aggregate elasticity and clay content (as measured by sand equivalent) to the observed shrinkage cannot be distinguished by statistical methods alone. This is because the two factors correlate significantly with one another (coefficient of 0.80), that is, sands with low elastic moduli tend also to have low sand equivalents and both, therefore, would be expected to influence shrinkage in the same direction and in unison.

The lower dynamic modulus of elasticity for the concretes with low sand equivalent values tends to show an effect of the active minus No. 200 mesh particles in the hardened concrete. These particles may offer less restraint to the shrinking paste thereby accounting for some of the increased shrinkage not directly attributable to higher water-cement ratios.

Durability of Air-Entrained Concretes

Specimens from batches A13 and A15 through A19 were subject to 400 cycles of slow freezing and thawing in a chest-type freezer. Only very slight surface deterioration was observed and the results were inconclusive. The specimens were stored until a later date when they were subjected to freeze-thaw testing according to ASTM C290. Deterioration of most of these specimens was not indicated by fundamental frequency determinations but did show itself in changes in weight due to surface deterioration. The exceptions were the specimens containing clay with a 640 LL (batch A19). These specimens completely disintegrated after 40 cycles and were removed from testing. Figure 8 shows the weight loss after 300 cycles (except from batch A19) of ASTM C290 testing, and Figure 9 shows these specimens after completion of testing.

The tests indicate an insignificant loss in durability of specimens containing fine aggregates with sand equivalent values of 80 and 81 when the proper amount of air is entrained in the concrete.

SUMMARY AND CONCLUSIONS

The conclusions developed from this study are based on a limited number of aggregates and concrete batches. Care should be exercised in extending these conclusions to materials other than those studied.

It has been found that the activity as well as the amount of the minus No. 200 mesh fraction of concrete aggregates affects the properties of concrete. Both activity and amount are reflected in the sand equivalent value but not in the loss by decantation (2). Clay fractions in concrete aggregate affect concrete properties primarily through their effect on water demand. Concrete strength and shrinkage correlate to a high degree with sand equivalent value and to a slightly lesser degree with water-cement ratio indicating the possibility that the sand equivalent test indicates properties of the aggregate that are not accounted for solely by the aggregate's water demand in concrete.

The freeze-thaw durability of the concretes studied is related to the sand equivalent value. Decreases in the sand equivalent value bring about decreases in the freeze-thaw durability of the concretes. With the exception of batch A19, attrition of the surface reflected by loss in weight was the only apparent indicator of deterioration.

Research reported here and elsewhere (2, 6) has shown that the quality of aggregates can be increased considerably during processing by more thorough cleaning.

The need for sufficient processing to produce a relatively clean aggregate is emphasized by considering the quantitative effects on the properties of the concretes tested. The data developed indicate that for a given fine aggregate, as the sand equivalent value changes from 60 to 80, the concrete properties will exhibit the following changes:

1. Gain in 7-day compressive strength of 15 percent;
2. Gain in 28-day compressive strength of 16 percent;
3. Gain in 7-day modulus of rupture of 13 percent;
4. Gain in 28-day modulus of rupture of 12 percent;
5. Insignificant change in durability of air-entrained concrete (air content approximately 5 percent);
6. Decrease in relative 28-day shrinkage of 17 percent;
7. Decrease in relative 120-day shrinkage of 15 percent; and
8. Decrease in concrete mixing water demand of 9 percent.

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