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PELLETIZED EXPANDED-SLAG AGGREGATE FOR STRUCTURAL LIGHTWEIGHT CONCRETE

by

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INTRODUCTION

Early in 1969, the Mines Branch was asked by the management of the National Slag Limited to assist in evaluating newly developed pelletized expanded-slag aggregate for structural lightweight concrete.

Until 1968, the expanded-slag aggregate in Hamilton, Ontario, was produced from the Dofasco* blast furnace slag by means of the pit process. The produced foamed lightweight material, broken in large chunks, was trucked to the nearby located slag processing plant of National Slag Limited where it was crushed and sized for use as aggregate in lightweight concrete. This material was angular, resulting in harsh mixes, unsuitable for use in structural concrete. Thus, about 95 per cent of the production was supplied to the lightweight concrete block manufacturers.

Since 1968, National Slag Limited has been producing improved expanded-slag aggregate in the form of coated and rounded cellular pellets. Because of its shape and inherent strength, this material is an excellent lightweight aggregate.

A large shipment of graded pelletized expanded-slag aggregate was received in January, 1972, and a project was started immediately to evaluate it as an aggregate for structural lightweight concrete.

PELLETIZED EXPANDED-SLAG AGGREGATE

This type of expanded-slag aggregate is being produced by a special quenching process. The resulting particles are glassy expanded slag pellets

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* Dominion Foundries and Steel Limited, Hamilton, Ontario.

between 100-mesh and 3/8-inch size. To supplement the proportions and correct the grading of the fine aggregate, the plus 3/8-inch pellets are crushed to sand sizes.

Gradings of expanded-slag coarse and fine aggregates as well as of natural sand are shown in Table 1.

TABLE 1

Gradings of Aggregates
(per cent passing)

Sieve Sizes	Expanded Slag (National Slag Ltd.)		Natural Sand (West Paris)
	C.A.*	F.A.**	
1/2-inch	100.0		
3/8-inch	92.5		
1/4-inch	50.0		
No. 4	26.0	100.0	97.0
No. 8		82.0	87.0
No. 16		41.0	72.0
No. 30		18.0	49.0
No. 50		8.0	17.0
No. 100		3.0	5.0
No. 200		1.0	2.0
Fineness Modulus:		3.48	2.73

* C.A. - coarse aggregate
** F.A. - fine aggregate

Other physical properties of the aggregates are shown in Table 2.

TABLE 2

Physical Properties of Aggregates

Properties	Expanded Slag (National Slag Ltd.)		Natural Sand (West Paris)
	C.A.	F.A.	
Absorption, per cent	9.2	7.0	1.1
Specific Gravity (bulk, SSD*)	1.69	2.12	2.65
Unit Weight, lb/cu ft (loose, dry)	52.5	67.7	103.0

* SSD - saturated, surface-dry condition

CONCRETE MIXES

Two 5-mix test series, for the all-lightweight (Series A) and for the semi-lightweight (Series B) concrete were designed to cover the strength range for structural concrete between 2000 and 6000 psi. Concrete mixes with the cement in increments of about 100 lb were designed according to exploratory work done in the laboratory of the Red-D-Mix Concrete Limited of Hamilton. A technician of that company was assigned to this laboratory to provide the available information for the design and preparation of the two mix series. Concrete mixes were made and the 6 x 12-in. test cylinders were cast between the 10th and 14th of January, 1972.

Materials

Aggregates

Both coarse and fine pelletized expanded slag and natural sand (from Paris, Ontario) were supplied in bags by National Slag Limited in gradings shown in Table 1; other physical properties are shown in Table 2.

In Series A mixes, only expanded slag was used as aggregate. In Series B, natural sand replaced expanded slag as fine aggregate.

Cement

A normal (CSA Type 10) portland cement was provided by Canada Cement Lafarge Ltd. from Plant No. 3 in Hull, Quebec. Chemical analysis and physical properties of the cemtn are given in the report attached as Appendix I.

Admixtures

(a) A water-reducing agent of the amino-acid type (Porzite-L77) was used in all mixes (0.85 cc per lb or 3 oz per 100 lb of cement),

(b) An air-entraining agent of a neutralized vinsol resin type (NVR), a half-strength product, was added in amounts required to maintain the air entrainment in concrete mixes within 7 ± 1½%. The amount of NVR added was between 0.12 and 0.25 cc per lb in Series A mixes and between 0.3 and 0.4 cc per lb of cement in Series B mixes.

Both admixtures are manufactured by Sternson Company of Brantford, Ontario.

Preparation of Concrete Test Mixes

The preparation of the test mixes, in accordance with specifications of the company, was supervised by a technician provided by National Slag Limited. Each mix was prepared as a 2-cu-ft batch. Aggregates were weighed-in as received and then soaked in water for 24 hr. By determining the moisture per cent of aggregate as received and its absorption value, its SSD weight was determined and the amount of free water in each mix was calculated. Mix proportions calculated on the SSD basis for the all-lightweight concrete Series A are given in Table 3, and for the semi-lightweight Series B in Table 4.

A counter-current, Lancaster type, 2-cu-ft mixer was used. After all material had been added, the constituents were mixed for 2 min, allowed to rest in the mixer for 1 min, then re-mixed for 2 min. The whole series of 5 mixes were made within 3 hr.

Properties of Freshly Mixed Concrete

The properties of the freshly mixed concrete, i.e., slump, air content, unit weight, temperatures of concrete, and the air in the mixing room, for each mix, are given in the second part of Table 3 for the all-lightweight and in Table 4 for the semi-lightweight concrete.

The air content of the concrete was determined twice - by the pressure method (ASTM Standard Method C 231) and by the volumetric method (ASTM Standard Method C 173) - using both pressure meter and roll-a-meter apparatus.

TABLE 3

Mix Data for All-Lightweight Concrete
Series A
Aggregates C.A.: 3/8-inch expanded slag pellets
F.A.: -No.4 expanded slag fines

Mix No	Mix Proportions, per 1 cu yd of Concrete						Characteristics of Freshly Mixed Concrete						
		Free	Aggregates, SSD		Admixtures			Air, %		Unit	Water-	Temperature	
	Cement, lb	water, lb	C.A. lb	F.A. lb	AEA* cc	WRA** cc	Slump, in.	Press. Meter	Roll-A Meter	Weight lb/cu ft	Cement Ratio	Concrete °F	Room °F
A-1	530	305	871	1264	11.0	35.0	3/4	11.5	11.0	110.0	0.58	75	72
A-2	615	303	945	1172	6.0	40.0	1	9.6	7.2	112.4	0.49	74	72
A-3	713	315	978	1084	7.5	48.0	1-3/4	9.0	6.0	114.8	0.44	74	77
A-4	825	330	969	976	11.5	56.0	2-1/4	8.9	6.2	114.8	0.40	74	77
A-5	915	345	981	913	14.0	60.0	2-1/2	8.5	5.3	116.8	0.38	75	77

* AEA: Air-entraining agent, NVR (half-strength) } A Sternson product,
** WRA: Water-reducing agent, L77 (amino-acid type) } (cc per 2 cu ft batch)

TABLE 4

Mix Data for Semi-Lightweight Concrete

Series B

Aggregates—C.A.: 3/8-inch expanded slag pellets
F.A.: -No. 4 natural sand

Mix No.	Mix Proportions, per 1 cu yd of Concrete						Characteristics of Freshly Mixed Concrete						
		Free	Aggregates, SSD		Admixtures			Air, %		Unit	Water-	Temperature	
	Cement, lb	water, lb	C.A. lb	F.A. lb	AEA* cc	WRA** cc	Slump, in.	Press. Meter	Roll-A Meter	Weight, lb/cu ft	Cement Ratio	Concrete °F	Room °F
B-1	357	334	854	1715	9.0	26.0	1-1/2	7.5	6.0	120.8	0.94	73	72
B-2	456	327	863	1644	13.0	33.0	3-1/2	8.4	6.8	122.0	0.72	73	74
B-3	563	309	859	1564	18.5	41.0	3	8.8	7.3	122.4	0.55	73	75
B-4	680	320	872	1468	23.0	50.0	2-1/2	8.4	7.5	123.6	0.47	73	74
B-5	874	339	875	1282	30.0	64.0	2-1/2	8.4	7.0	124.8	0.39	75	75

* AEA: air-entraining agent, NVR (half-strength), } A Sternson product,
** WRA: water-reducing agent, L77 (amino-acid type) } (cc per 2 cu ft batch)

Of the two air meters, the pressure meter showed higher air content than the roll-a-meter because of the porosity of the aggregate. For lightweight concrete, the latter type of air meter should be used.

The 0.25-cu-ft bowl of the pressure meter was used as a measure to determine unit weights. Concrete was placed into the measuring container in two layers. Each layer was compacted by inserting a 1 1/8-in.-diam. internal vibrator for about five seconds.

PREPARATION AND CURING OF TEST SPECIMENS

The prime objective of the two mix series A and B was to investigate the strength properties of lightweight and semi-lightweight concrete made with the pelletized expanded-slag aggregate. With this in mind, only 6 x 12-in. cylinder test specimens were prepared. Altogether, ten cylinders were cast from each batch, scheduled for testing as follows:

Number of Cylinders	Test Age, days	Curing Conditions
2	7	Standard moist curing
2	28	" " "
2	28	Air-dry after initial 7 d moist curing
2	1 yr } *	
2	1½ yr } *	

TEST RESULTS

Besides compressive strength determinations, the density of hardened concrete was calculated. After initial seven-day moist curing, each test cylinder was weighed in SSD condition in air and then in water. The difference in weight provided basis for calculating the volume of each test cylinder. Thus

* To be reported at a later date

wet density was determined at 7 days, and both the wet and dry density at 28 days.

The results of density and compressive strength determinations of concrete at 7 and 28 days are compiled in Table 5 separately for each series A and B.

DISCUSSION

Mix Design

In the mix design for structural lightweight concrete, the main considerations are the density and strength requirements. From the construction aspect, workability and finishability of freshly placed concrete must also be considered.

Proportions of ingredients used in each mix, as given in Tables 3 and 4, have been plotted on two graphs for both Series A and Series B (Appendices II and III) as separate curves for coarse and fine aggregates, amounts of the free mix-water, and unit weights. Also shown is the 28-day compressive strength curve obtained on dry test cylinders. All these curves are related to the corresponding amount of cement per cu yd for each mix.

These graphs thus are representing the mix designs used in both Series A and B which consist of five mixes each. The strength curve makes it possible to derive mix proportions for any strength specified within given ranges.

Let us assume we wish to design a 4000-psi concrete with 15% over-strength. A dashed line is drawn horizontally through the 4600-psi mark to intersect the strength curve. By drawing a vertical line through the point of intersection, the amount of each ingredient in pounds may be obtained. The

TABLE 5

Density and Compressive Strength Results*

All-Lightweight Concrete

Series A

Mix Nos.	Cement Content, lb /cu yd	Density lb/cu ft		Compressive Strength, psi*		
		7-day (wet)	28-day (dry)	7-day (wet)	28-day (wet)	28-day (dry)
A1	530	114.6	110.3	2950	3545	3785
A2	615	116.5	112.9	3525	4425	4475
A3	713	118.2	115.1	4385	5060	5150
A4	825	118.5	115.7	5025	5575	5325
A5	915	119.7	117.0	5360	6115	6010

Semi-Lightweight Concrete

Series B

B1	357	126.1	120.0	1840	2255	2285
B2	456	125.8	120.7	2660	3430	3415
B3	563	126.1	122.4	3705	4235	4122
B4	680	126.0	123.3	4255	4925	4925
B5	874	126.4	124.2	4950	5950	5270

* Each result is the average of two 6 x 12-in. cylinders.

mix proportions for the 4000-psi concrete obtained for both Series A and B per cubic yard are as follows:

	Series A (All-Ltw)	Series B (Semi-Ltw)
Cement, lb	630	610
Coarse Aggr, lb	943	870
Fine Aggr, lb	1160	1525
Water, lb	307	310
Total	3040	3315
Admixtures: WRA-(L77), oz	19	18
AEA-(NVR), oz	3	8

Density or Unit Weight

Density and strength are the most important parameters for structural lightweight concrete.

In this project, the densities of hardened concrete were determined on the 7-day wet-cured and 28-day air-dried test cylinders. The results are compiled in Table 5 on both Series A and Series B for each mix.

The density of lightweight concrete depends mainly on the density of aggregate which is higher for the pelletized than for foamed expanded slag. Unit weights of the loose, oven-dry material, used in this project, are shown in Table 2 as 52.5 and 67.7 lb/cu ft for the coarse and fine aggregate, respectively. It appears that the unit weights of pelletized-slag coarse and fine aggregate are close to the respective maximum weight limits of 55 and 70 lb/cu ft, as specified by the ASTM Designation C 330[1].

Though definition of the structural lightweight-aggregate concrete stipulate that the 28-day air-dry density should not exceed 115 lb/cu ft, it is understood that job specifications may allow densities up to 120 lb/cu ft[2,3].

The results compiled in Table 5 show 28-day air-dry densities ranging from 110.3 to 117.0 lb/cu ft for all-lightweight concrete of Series A, and from 120.0 to 124.2 lb/cu ft for semi-lightweight concrete of Series B. Apparently the density of Series B concrete mixes exceeds the maximum unit weight specification.

Data available here from another series of 18 all-lightweight concrete 4 x 8-in. test cylinders (cement content 625 lb/cu yd) indicate that the average 28-day unit weight of the air-dried concrete has reduced from 111.68 lb to 108.87 lb, or by about 3 lb per cu yd after a further 2 months of air-drying in a dry-storage room at a relative humidity (R.H.) of 40 ± 10%.

Therefore, 3-months' drying would make this type of concrete more acceptable as lightweight concrete.

Strength

Compressive strength results compiled in Table 5 are plotted separately for Series A and B on plots, shown in Appendices IV and V, of strength versus cement content for wet- and dry-cured test cylinders. The 28-day strength curves indicate that, for leaner mixes, the dry-cured test specimens are stronger than the moist-cured ones. However, for richer mixes, the reverse is true. Apparently lack of moisture in the dry-cured concrete causes insufficient hydration of cement in rich mixes and retards the proper strength development.

To compare the strength development, 28-day dry compressive strength curves for both Series A and B are plotted (Appendix VI). It shows that, for mixes with cement content below 650 lb/cu yd, the strength of semi-lightweight concrete is higher than that of all-lightweight concrete. However, for the richer mixes again, the reverse is true and a higher strength was obtained on the all-lightweight concrete for cement contents exceeding 650 lb/cu yd. This seems to contradict the normal trend in which semi-lightweight concrete produces higher strength than all-lightweight concrete, when the same cement amount is used per yard. To substantiate the above findings, repeated test series will be required.

Excessive density of semi-lightweight concrete makes its use for structural applications uneconomical. With a saving in weight of only 20 lb per cu ft of concrete, it is hard to justify the higher cost of a lightweight concrete over the cost of conventional concrete.

CONCLUSIONS

1. Excellent structural all-lightweight concrete, having a 28-day compressive strength of 5000 psi and over, with an air-dry density from 110 to 117 lb/cu ft, can be produced by using pelletized expanded-slag aggregates.
2. If expanded-slag fine aggregate is available, natural sand should not be used as fine aggregate; this will avoid the excessive increase in density of concrete.

REFERENCES

1. ASTM Designation: C 330-69, "Standard Specification for Lightweight Aggregates for Structural Concrete".

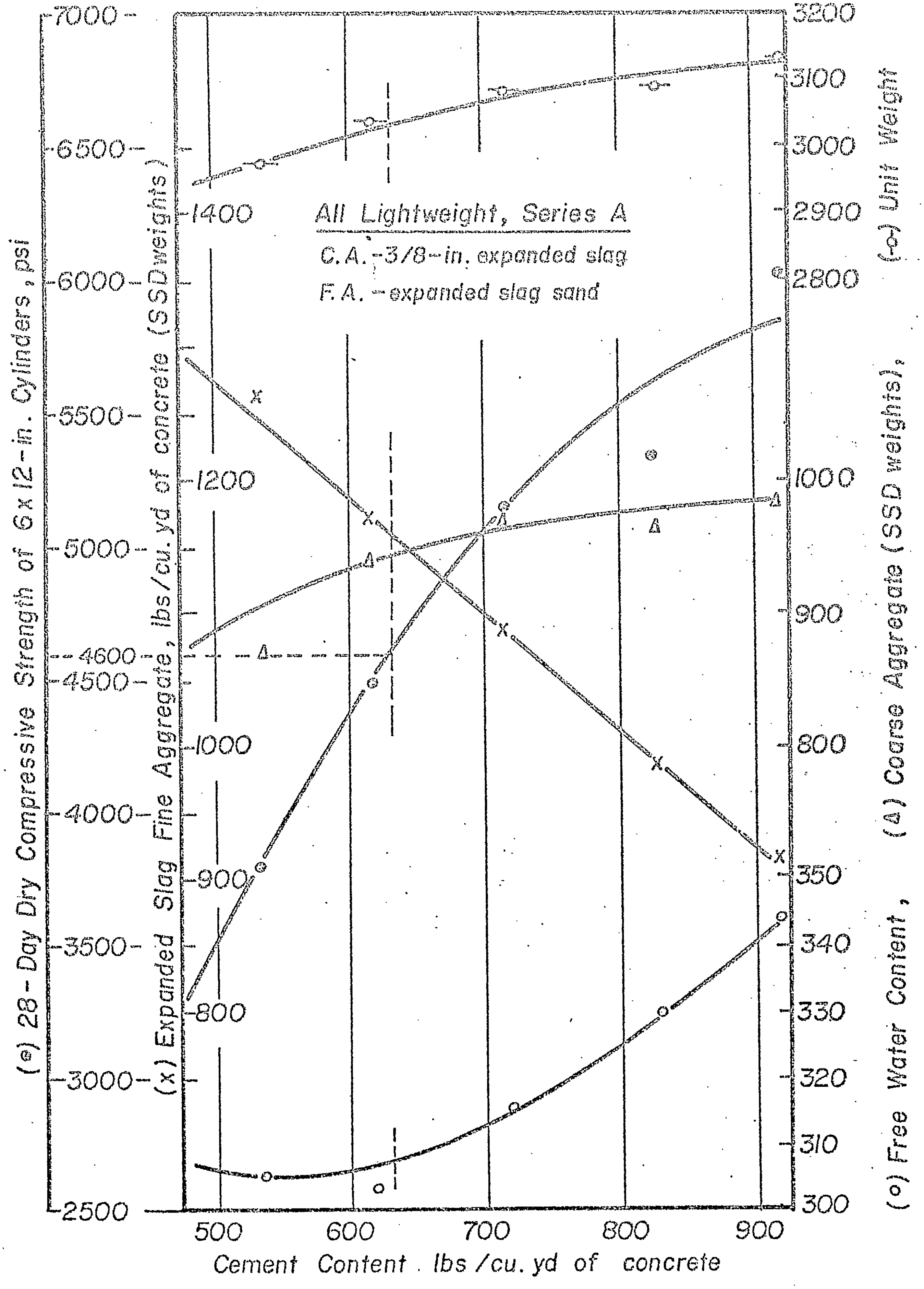
2. ACI 318-71, "Building Code Requirements for Reinforced Concrete", 2.1 - Definitions, Concrete, Structural Lightweight.

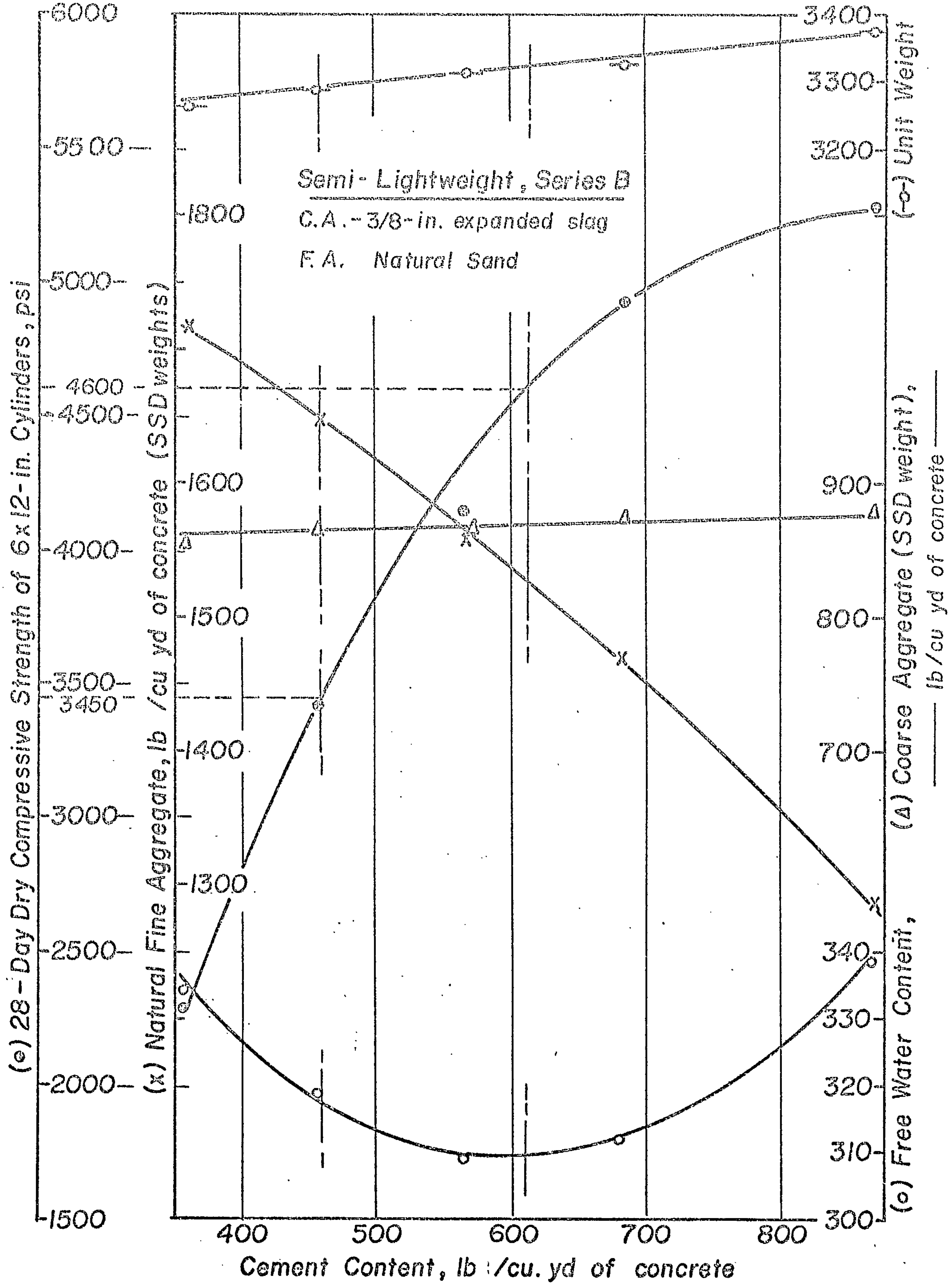
3. ACI Committee 213, "Guide for Structural Lightweight Aggregate Concrete", 1.5 - Definition of structural lightweight aggregate concrete.

NGZ/KEP/am

Chemical Analysis of Cement
(CSA Type 10)

Chemical Constituents		Per Cent (by weight)
Silica	(SiO_2) ----	20.40
Alumina	(Al_2O_3) ----	5.51
Iron Oxide	(Fe_2O_3) ----	2.71
Calcium Oxide	(CaO), Total	64.23
Calcium Oxide	(CaO), Free	0.64
Magnesium Oxide	(MgO) ----	3.00
Sulphur Trioxide	(SO_3) ----	2.14
Sulphur	----	0.0
Iron	----	
Manganese	----	
Loss on Ignition	----	0.31
Insoluble Residue	----	0.16
	Total:	99.10


All Lightweight, Series A
C.A. - 3/8-in. expanded slag
F.A. - expanded slag sand
(⊙) 28-Day Dry Compressive Strength of 6 x 12-in. Cylinders, psi
(x) Expanded Slag Fine Aggregate, lbs/cu. yd of concrete (SSD weights)
(-o-) Unit Weight
(Δ) Coarse Aggregate (SSD weights),
(o) Free Water Content,
7000
6500
6000
5500
5000
4600
4500
4000
3500
3000
2500
1400
1200
1000
900
800
3200
3100
3000
2900
2800
1000
900
800
350
340
330
320
310
300
500
600
700
800
900
Cement Content. lbs/cu. yd of concrete



Semi- Lightweight, Series B
C.A.- 3/8-in. expanded slag
F.A. Natural Sand
(⊖) 28-Day Dry Compressive Strength of 6 x 12-in. Cylinders, psi
(x) Natural Fine Aggregate, lb /cu yd of concrete (SSD weights)
(-o-) Unit Weight
(Δ) Coarse Aggregate (SSD weight), lb/cu yd of concrete
(o) Free Water Content,
Cement Content, lb /cu. yd of concrete
6000
5500
5000
4600
4500
4000
3500
3450
3000
2500
2000
1500
1800
1600
1500
1400
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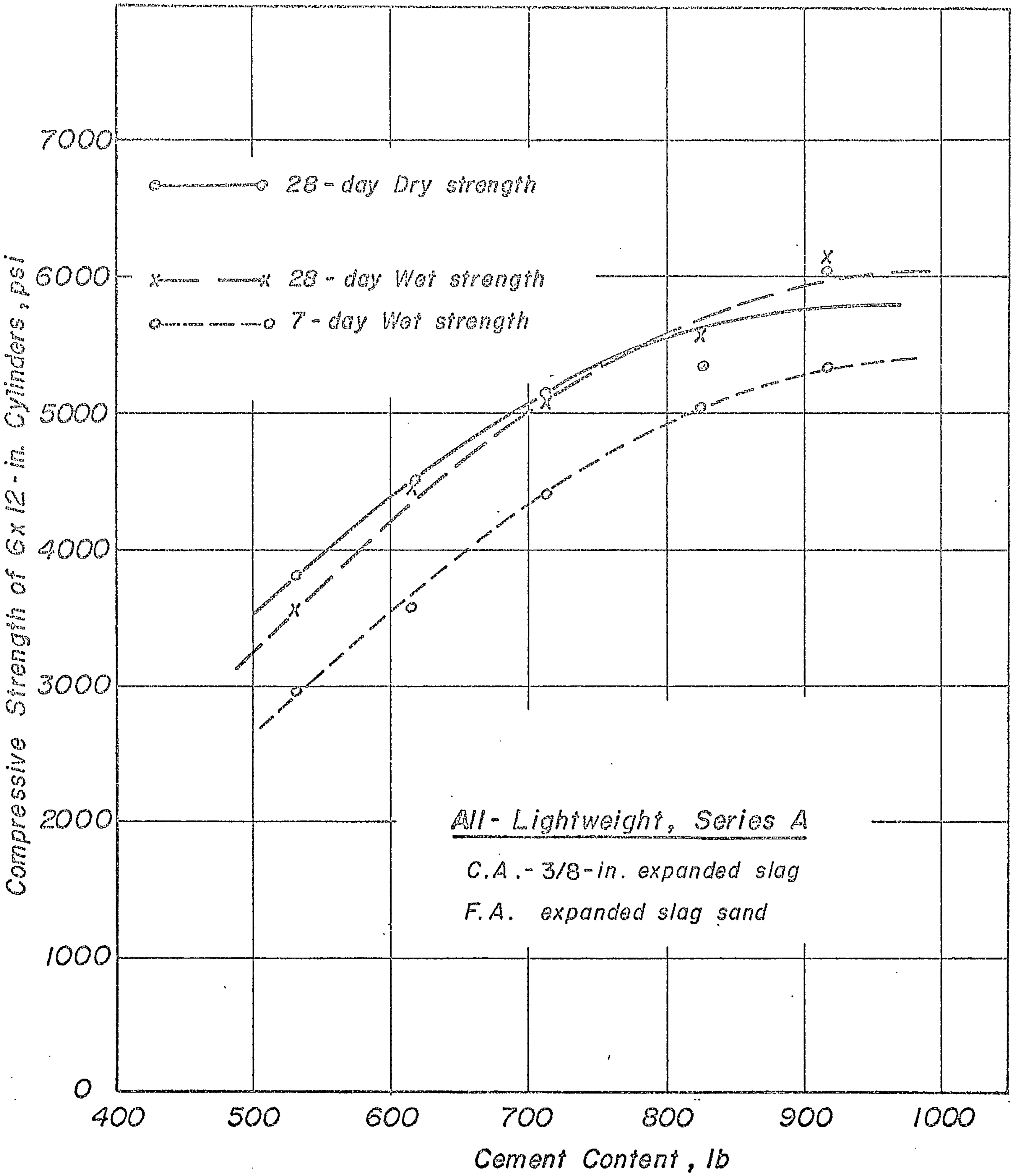
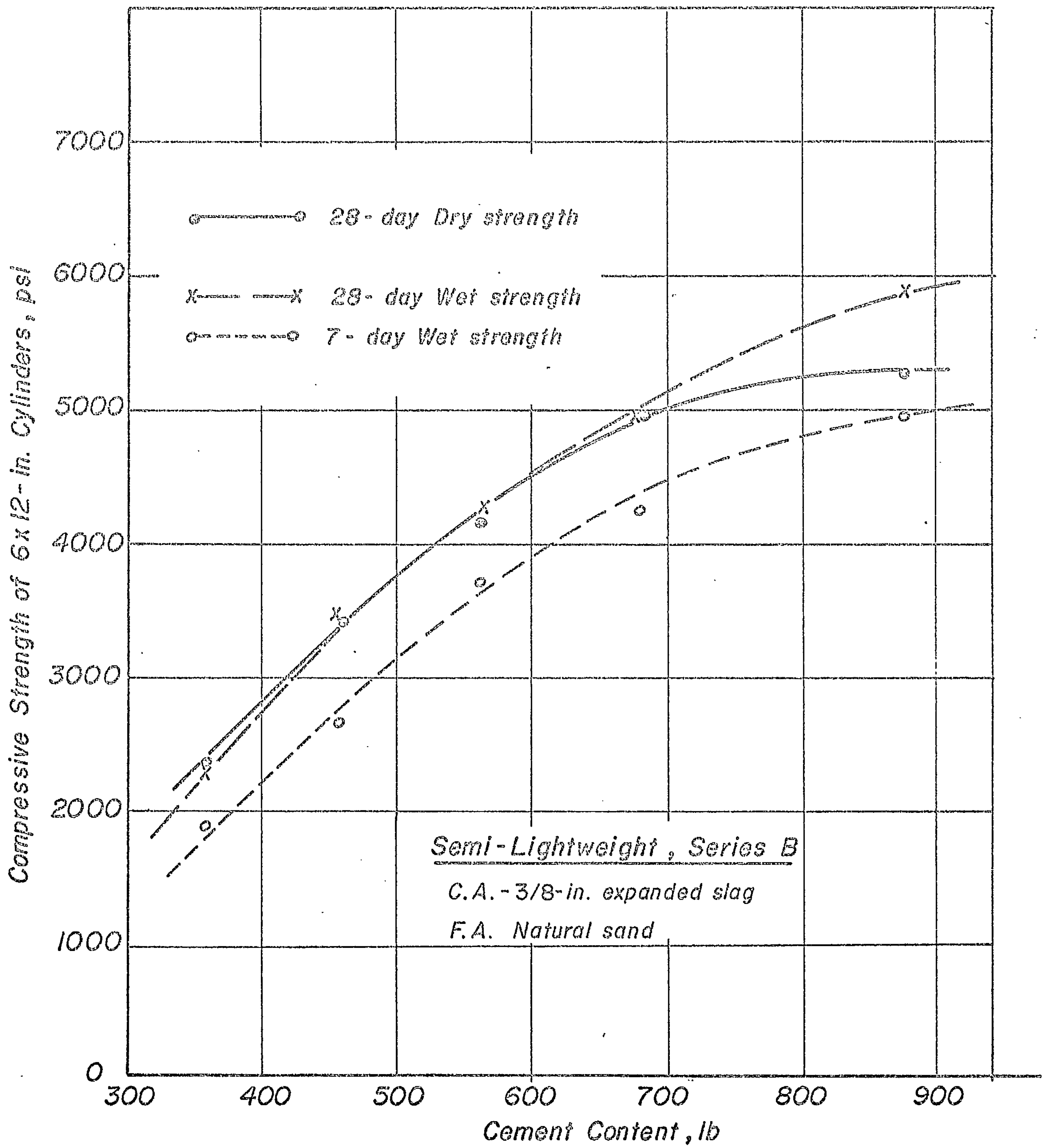
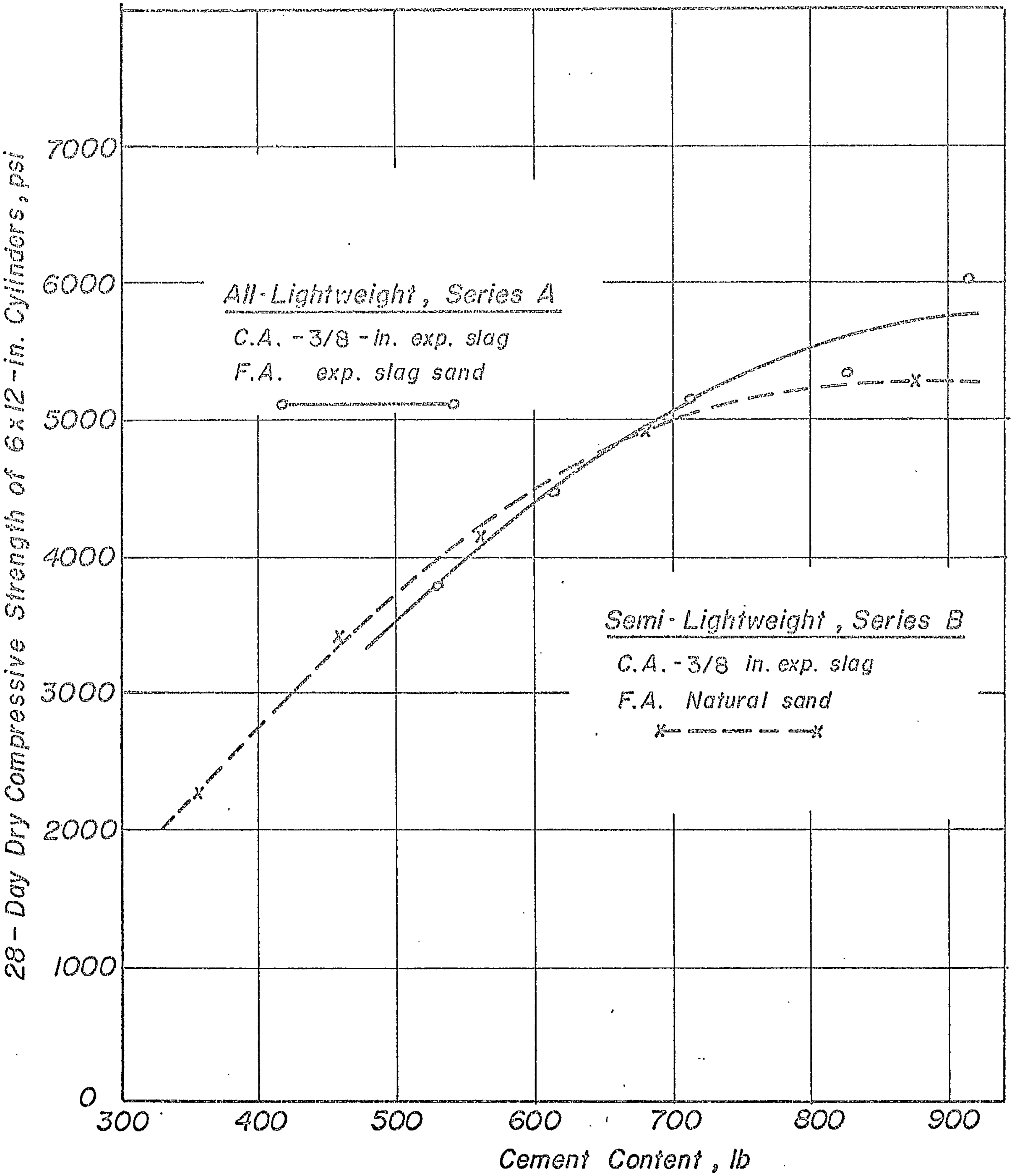
400
500
600
700
800



28-day Dry strength
28-day Wet strength
7-day Wet strength
All-Lightweight, Series A
C.A.-3/8-in. expanded slag
F.A. expanded slag sand
Compressive Strength of 6x12-in. Cylinders, psi
7000
6000
5000
4000
3000
2000
1000
0
400
500
600
700
800
900
1000
Cement Content, lb



7000
6000
5000
4000
3000
2000
1000
0
300
400
500
600
700
800
900
Compressive Strength of 6 x 12 - in. Cylinders, psi
Cement Content, lb
28 - day Dry strength
28 - day Wet strength
7 - day Wet strength
Semi - Lightweight, Series B
C.A. - 3/8-in. expanded slag
F.A. Natural sand



28 - Day Dry Compressive Strength of 6 x 12 - in. Cylinders, psi
0
1000
2000
3000
4000
5000
6000
7000
300
400
500
600
700
800
900
Cement Content, lb
All-Lightweight, Series A
C.A. - 3/8 - in. exp. slag
F.A. exp. slag sand
Semi-Lightweight, Series B
C.A. - 3/8 in. exp. slag
F.A. Natural sand