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A lightweight concrete specially suited for deep ocean applications was tested for its strength properties and compared to similar regular lightweight concrete. The new concrete used lightweight aggregate particles (expanded shale) which were filled with a polymeric material. The polymer-filled aggregate (PFA) was conventionally mixed with portland cement and water to make the lightweight concrete. Four concrete mixes were tested. In general, the PFA concrete, compared to regular lightweight concrete, has an equal unit weight in a

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seawater saturated condition and exhibited increases in compressive strength of 26%, split tensile strength of 4%, elastic moduli of 4% and an equal Poisson's ratio. The strongest mix for PFA concrete had a compressive strength of 6,580 psi, compared to 5,200 psi for regular lightweight concrete, at an age of 28 days under continuous fog curing. Both mixes have a weight savings of 40%, compared to that of normal weight concrete in a submerged, saturated condition. A discussion of cost is presented and shows that the in-place structural cost of PFA concrete would be about 30% greater than normal concrete.

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A lightweight concrete specially suited for deep ocean applications was tested for its strength properties and compared to similar regular lightweight concrete. The new concrete used lightweight aggregate particles (expanded shale) which were filled with a polymeric material. The polymer-filled aggregate (PFA) was conventionally mixed with portland cement and water to make the lightweight concrete. Four concrete mixes were tested. In general, the PFA concrete, compared to regular lightweight concrete, has an equal unit weight in a seawater saturated condition and exhibited increases in compressive strength of 26%, split tensile strength of 4%, elastic moduli of 4%, and an equal Poisson's ratio. A discussion of cost is presented and shows that the in-place structural cost of PFA concrete would be about 30% greater than normal concrete.

CONTENTS

INTRODUCTION

The first application for lightweight concrete, in 1919, was for a concrete ship 434 feet long named the USS SELMA. During World Wars I and II, hundreds of ships and barges were made of lightweight concrete. More recently, normal weight concrete has found considerable application in energy-related offshore structures, such as oil drilling and production platforms. Proposals abound for other applications, such as submerged oil production enclosures, seafloor fuel storage tanks, and even liquefied natural gas transport ships. In any one of these applications, a construction material lower in unit weight than normal weight concrete would be beneficial to the designer in planning a structure of less draft or higher payload capacity.

An application with major economic implications for the United States is related to future structures for ocean thermal energy conversion (OTEC). OTEC uses the temperature difference between the warm surface water and the cold deep ocean water to evaporate and condense a liquid for driving a turbine to generate electricity. Not only is a massive floating platform required to support the hardware on the surface, but an enormous cold water pipe that may be on the order of 60 feet in diam and 2,000 feet long is also required. The pipe must be "flexible" to reduce bending moments during periods of rough weather. Hence, it would be helpful if the construction material had a low elastic modulus.

Regular lightweight concrete is a candidate construction material for OTEC. Compared to normal weight concrete, lightweight concrete potentially can save weight of 40% while maintaining a compressive strength of 5,000 psi and better.

This study investigated a material that would also have a weight saving of 40%; but possibly with a compressive strength greater than that of regular lightweight concrete. This material, a lightweight portland cement concrete, used specially prepared aggregate. The special aggregate was regular lightweight aggregate that had its void volume filled with a polymeric material.

There were several reasons for filling just the aggregate and not the entire concrete material:

1. The specific gravity of polymer is approximately equal to that of seawater. Hence, aggregate filled with polymer would have approximately the same weight as seawater-saturated regular lightweight aggregate. This means that the in-water unit weight of concrete saturated from deep ocean exposure would be the same if polymer-filled aggregate (PFA) or regular lightweight aggregate were used.

2. The compressive strength of PFA concrete should be greater than that of regular lightweight concrete because the individual aggregate particles are stronger. Concrete strength is usually controlled by the strength of the aggregate particles. Regular lightweight aggregate particles have about 50% void volume, which is the cause of a relatively weak particle strength. PFA particles have the void volume filled with polymer which imparts added strength to the particles and should result in higher compressive strengths for lightweight concretes.

3. The elastic moduli for PFA and regular lightweight concrete will be similar. This is beneficial for applications which require a relatively low elastic modulus and a nonlinear material response near ultimate conditions.

Polymer impregnation techniques are available for filling all the voids in the concrete (i.e., the cement voids and the aggregate voids), but this method causes the elastic modulus to increase to about twice that of nonimpregnated concrete and the material exhibits brittle behavior at near ultimate load conditions. These are undesirable characteristics in some cases. The desirable features of impregnating the concrete with polymer are that three- to four-fold increases in compressive strength and two-fold increases in tensile strength can be expected. Research on polymer impregnated concrete is reported elsewhere.* This report was concerned with determining the strength properties of PFA lightweight concrete.

SCOPE

In this test program four mix designs of PFA concrete and corresponding control specimens of regular lightweight concrete (same aggregate but not polymer-filled) were investigated. Fifteen specimens 4 inches in diameter by 8 inches long were made for each batch of concrete. Six specimens were tested in compression, of which three were instrumented for strain to obtain elastic moduli and Poisson's ratio data; five specimens were tested in split tension; and two specimens each were placed in a 30% relative humidity (RH) environment and a pressure vessel at 500 psi to obtain unit weight data.

MATERIALS

Regular Lightweight Aggregate

Regular lightweight aggregate for structural grade concretes is typically a manufactured product made by using heat to expand naturally occurring shales, clays, and slates and industrial by-products such as clay and pelletized fly ash. In all cases, the aggregates are light in weight because of an internal cellular structure of the individual aggregate particles.

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*American Concrete Institute. ACI SP-58: Polymers in Concrete - International Symposium. Detroit, Mich., 1978, 426 pp.

The only difference between lightweight concrete and normal weight concrete is that some or all of the "hard rock" sand, gravel, or crushed rock is replaced by lightweight aggregate. Typically, the unit weight of normal weight concrete is 150 pcf while lightweight concrete ranges from 90 to 120 pcf.

This study used expanded shale lightweight aggregate manufactured under the brand name of Rocklite (Ventura, Calif.). Five aggregate sizes - 1/2-inch, 3/8-inch, 5/16-inch, coarse sand, and fine sand - were used (Figure 1). A sieve analysis for the aggregate is given in Table 1; Table 2 gives some physical properties of the aggregates. Of interest are the data that show that the void volume ranged from 47% to 54% for the aggregate sizes from coarse sand to 3/8 inch, respectively. The internal structure of an aggregate particle is shown in Figure 2.

Prior to mixing the regular lightweight concrete, the aggregate was batched according to weight and then saturated with freshwater. In the saturation procedure, air was evacuated from the aggregate for 20 minutes, and then the aggregate was submerged in water for about 24 hours. At this stage, the aggregate was placed in a pressure vessel and subjected to 10,000 psi for 15 hours which gave assurance that saturation was complete.

It is highly unlikely that the hydrostatic pressure harmed the aggregate. The void volume is interconnected and easily accessible to water under pressure. A pilot study on saturation gave the data shown in Figure 3. Soaking the aggregate after evacuation was not sufficient to saturate the particles; however, as soon as 250 psi overpressure was applied the aggregate became completely saturated in 48 hours. The coarse sand and 5/16-inch aggregate showed the same behavior as that of 3/8-inch aggregate (see Figure 3), except for different maximum water absorption values.

Polymer-Filled Aggregate (PFA)

Regular lightweight aggregate was impregnated with polymeric materials to make PFA. Brookhaven National Laboratory performed the impregnation. This organization has conducted similar work on impregnating poor quality "hard rock" aggregate.*

The impregnation process used a monomer (liquid) to impregnate the voids in the aggregate and then, by using heat, to polymerize the liquid into a solid. The monomer system was, by weight, 83% methyl methacrylate (MMA), 5% trimethylolpropane trimethacrylate (TMPTMA), and 12% polymethyl methacrylate (PMMA). The aggregate was oven-dried at 150°C for 24 hours to remove free moisture from the pores. The aggregate was then placed in a chamber and evacuated for 18 hours; at that point monomer was introduced into the chamber.

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*Brookhaven National Laboratory. Report No. BNL-25396: Improvement of wear-resistance properties of natural aggregates by materials impregnating, by R. P. Webster and J. J. Fontana. Upton, N.Y., Sep 1978, 34 pp.

Impregnation occurred for 3 hours at 15 psig overpressure. Excess monomer was drained and hot water (85° to 95°C) was introduced into the chamber to initiate polymerization of the monomer. After 4 hours the aggregate was removed to an oven for heating overnight at 110°C to assure complete polymerization.

Table 3 shows that after the first impregnation the percentage weight gain of polymer loading in the aggregate could be increased by a second impregnation. A second impregnation was conducted, which brought the polymer loading values closer to that calculated as the maximum. The data showed that a certain portion of the void volume (about 7.5%, 8.6%, and 12.7% by volume for the coarse sand, 5/16-inch and 3/8-inch aggregate, respectively) remained empty after the second impregnation. Figure 4a shows a scanning electron microscope photograph at 15 times magnification of a PFA aggregate particle. Polymer in many of the voids is separated from the wall of the void as if shrinkage occurred during the polymerization process. For comparison, Figure 4b shows a regular lightweight aggregate particle.

Concrete

Table 4 gives the mix designs for the concrete. The basis for the designs of Mix no. 1 through 3 was manufacturers' technical literature.* Mix no. 4 was a modification of Mix no. 3 in which a greater proportion of large aggregate was used. The aggregate sizes were blended to meet ASTM specifications C-33 for grading of concrete aggregates.

The aggregate proportions in Table 4 are for regular lightweight particles in a dry or "as received" condition from the manufacturer. The manufacturer packages oven-dry material in paper sacks, but moisture is picked up by the aggregate during storage. The aggregate weights used during batching were from the slightly moisture-laden aggregates. Without having the oven-dry weights, the quantity of PFA to use in each batch could not be calculated using weighing methods. Therefore, a volume batching method was used.

Slump was used to control the quantity of water added to each batch of concrete. The significantly different water-to-cement ratios between PFA and regular lightweight concrete resulted from using the totally saturated condition of the regular aggregate and the nonsaturated condition of the PFA. The quantity of water added to the mixes was the amount used in calculating the water-to-cement ratio.

All specimens were fog-cured for 28 days prior to testing for strength or before placement in other environmental conditions for unit weight measurements.

EXPERIMENTAL PROCEDURES

The compressive strength tests were conducted on 4 by 8-inch cylinders in accordance with ASTM C-39, and splitting tensile strength

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*Lightweight Processing Co. Technical reference manual for rocklite concrete. Glendale, Calif., 1966.

tests in accordance with ASTM C-496. The modulus of elasticity and Poisson's ratios were obtained using the standard procedure in ASTM C-469.

In an attempt to obtain air-dry unit weights for the concrete, two specimens of PFA and regular lightweight concrete were placed in a 30% RH environment. Unit weights for saturated concrete were also desired, so two specimens of each were placed in a pressure vessel at 500 psi for periods of 14 to 17 days.

TEST RESULTS

Strength Results

Table 5 presents the results from the compressive and split tensile tests. In compression, the concrete mixtures increased in strength as the cement contents increased from 460 to 710 lb/cu yd (Mix no. 1 through 3). The cement content was the same for Mix no. 3 and 4 at 710 lb/cu yd, and the compressive strengths are essentially equal.

For the regular lightweight concrete, the maximum compressive strength f'_c averaged 5,200 psi. Failure was caused by rupture of the aggregate particles. For the PFA concrete, the maximum f'_c was 6,530 psi - an increase of 26% over that of regular concrete; failure in this case was caused by failure of the bond between the aggregate and cement matrix. Thus, the strength of the PFA concrete will increase with continued fog-curing while the regular concrete had attained its maximum strength limit. Figure 5 shows a photograph of the different types of failure modes. Even though the specimens in Figure 5 are from split tension tests, the same appearance was found for compression specimens. Thus, it is important to state that the strength difference between regular and PFA concrete will increase with age beyond the present 26%.

For split tensile strengths, the PFA concrete showed an average increase of only 4% over that of regular lightweight concrete. This was surprising because the failure modes are different (Figure 5); however, the test results are quite consistent. A split tensile strength of 500 psi appeared to be the limit for the concretes.

The elastic modulus for the PFA concrete was also 4% greater than that of the regular concrete. The stress-strain behavior for the concretes was quite similar (Figures 6 through 9). For the higher strengths, both types of concrete showed little nonlinear behavior before failure. The specimens showed predominantly vertical cracking behavior at failure.

The stronger aggregate particles of the PFA concrete probably contributed to a greater ultimate strain, which was an average 3,300 μin./in., compared to 2,750 μin/in. for the regular concrete. The ultimate strain values were also quite consistent.

Poisson's ratio varied considerably from test to test, which is typical for concrete. However, the overall average for the PFA and the regular concrete was the same at 0.25.

Unit Weights

Various unit weights for the concretes were obtained. Figures 10 through 13 show the unit weights as bar charts in comparing PFA and regular lightweight concrete. The environmental storage condition of 30% RH for 17 days after fog curing for 28 days did not produce a uniformly dry concrete throughout the specimens, so these unit weights have little meaning. The manufacturer's mix design information indicated that the approximate air-dry weights for the regular lightweight concrete would be 92, 94, and 95 pcf for Mix no. 1, 2, and 3, respectively. It was estimated that Mix no. 4 would be about 92 pcf because of the large proportion of coarse aggregate.

The air-dry unit weights for the PFA concrete were about 103, 106, 108, and 110 pcf for Mix no. 1, 2, 3, and 4, respectively.

The freshly mixed unit weights averaged about 112 pcf for the regular lightweight concrete where the aggregates were totally saturated before the concrete was mixed, while the PFA concrete had an average 109 pcf. The PFA was not water-saturated prior to mixing the concrete, which explained the lower densities; air voids had remained in the aggregate and about 10% of the original void volume was not filled with polymer.

The in-air unit weights for saturated concrete are shown in Figures 10 through 13. In the saturation procedure pressure was 500 psi for 14 to 17 days. On the average, the PFA concrete showed a unit weight increment of 0.7 pcf greater than that of the regular lightweight concrete. Theoretically, the increment should have been from 0.8 to 1.3 pcf because the specific gravity of polymer is 7.5% greater than that of seawater. In any event, the unit weight differences between the materials were small.

In summary, the unit weights for the regular lightweight concretes changed from about 94 to 114 pcf when going from the air-dry condition to the water-saturated condition. The high strength PFA concrete (Mix no. 3 and 4) showed unit weights that changed from 109 to 115 pcf when going from the air-dry to the water-saturated condition.

DISCUSSION

The significance of the test results is clear when compared to similar data for normal weight concrete. The advantage of using lightweight concrete in the ocean is to save weight. In a saturated condition, regular lightweight and PFA concrete have the same unit weight, so can be considered as lightweight concretes having a saturated unit weight of 115 pcf.

Normal weight concrete has an air-dry unit weight of about 145 pcf (without steel reinforcement) and a saturated unit weight of about 150 pcf. If lightweight concrete is used in place of normal weight concrete for such applications as the hull and superstructure of a floating platform, the weight saving is about 30% (using 145 pcf for normal weight concrete and an estimated 100 pcf for moisture-laden regular lightweight concrete). If the application is for submerged structural elements, such as beams, columns or shells (cold water pipe to OTEC), then the weight saving is 40% (saturated-in-seawater unit weights are 150 - 64 = 86 pcf for normal weight concrete and 115 - 64 = 51 pcf for lightweight concrete). This is a significant weight saving.

When comparing material strengths, the properties of normal weight concrete can vary considerably, depending on the mix design and type of aggregate. One mix design used recently by CEL and obtained from a local transit mix company used 658 lb/cu yd of portland type II cement, water-to-cement ratio of 0.46, and river gravel of 1 inch maximum size. The 28-day properties were: compressive strength, 6,060 psi; elastic modulus, 3.2×10^6 psi; and Poisson's ratio, 0.22. In comparison, the high strength regular lightweight concrete and the high strength PFA concrete had compressive strengths of 5,200 and 6,580 psi, respectively; and the elastic moduli were one-third lower. In essence, the strengths of PFA concrete and normal weight concrete were comparable. However, normal weight concretes can be designed for strengths of 8,000 to 9,000 psi, which appears to be beyond the capability of PFA concrete.

Cost is also important. Table 6 gives estimated costs for the aggregate, concrete, and in-place concrete costs. The PFA cost is about 54 times that of normal weight aggregate and 13 times that of regular lightweight aggregate. The added cost is that of polymer at about $1.00/lb, plus 20% for manufacturing. PFA concrete costs about 9 times as much as normal weight concrete and 6 times as much as regular lightweight concrete.

The most important cost parameter for comparison, however, is the in-place concrete cost. This cost is obtained by dividing the total structure cost by the total quantity of concrete. Typically, for an offshore concrete structure the in-place cost is about $1,000/cu yd. For simplicity, Table 6 shows the concrete material cost added to $1,000/cu yd to obtain the in-place concrete cost. For this case, PFA concrete costs 1.30 times that of normal weight concrete and 1.27 times that of regular lightweight concrete.

For certain applications, the material selection can have a major impact on life cycle cost through weight savings. For example, a structure such as OTEC would be a moored, floating platform which could benefit by a lighter-weight construction material for the hull and cold water pipe. The outside dimension of the hull is sized by the required displacement to support the hull, internal hardware, and cold water pipe. By reduction of the weight of the hull and cold water pipe, the outside dimension of the hull can be reduced. A considerable volume of material would be saved, which reduces first cost. In addition, the smaller sized hull will produce lower drag forces that will reduce the mooring forces. The mooring lines and anchors can be reduced in size for a major cost savings. Over the life of the structure, several mooring lines - and possibly anchors - will be required so the cost savings accumulate.

In summary, the in-place cost of PFA concrete is about 30% greater than that of normal weight concrete while the weight saving is 40%. Only an economic analysis of individual projects can show whether the use of PFA concrete is cost beneficial.

FINDINGS

1. The maximum compressive strength after 28 days of fog curing was 6,580 psi for PFA concrete as compared to 5,200 psi for regular lightweight concrete. This high strength mix design of PFA concrete was 26% stronger than that of regular lightweight concrete.

2. The maximum splitting tensile strength of PFA concrete was 520 psi or 4% greater than that of regular lightweight concrete.

3. The failure mode in compressive and tension for PFA concrete was a bond failure between cement and aggregate while the regular lightweight concrete had the aggregate particles fail. Thus, strength increases with age can be expected from the PFA concrete while the regular lightweight concrete had attained its limit.

4. The elastic modulus of PFA concrete was, on the average, 2.1×10^6 psi which was 4% greater than that of regular lightweight concrete. A Poisson's ratio of 0.25 was essentially the same for both types of concretes.

5. Both PFA and regular lightweight concrete have a saturated unit weight averaging about 115 pcf. For undersea applications, a weight saving of 40% is realized if either of these concretes replace normal weight concrete. Although PFA concrete costs about nine times that of normal weight concrete, the in-place structural cost is only about 30% higher.

ACKNOWLEDGMENTS

The assistance of the Brookhaven National Laboratory, and in particular Mr. Ron Webster, for impregnating the aggregate is acknowledged. Also, the assistance of our colleague, Mr. Robert Rail, is appreciated.

Table 1. Aggregate Sieve Analysis

Sieve Size	Percent Retained on Each Sieve for Following Aggregate Sizes --				
	1/2 in.[a]	3/8 in.	5/16 in.	Coarse Sand	Fine Sand[a]
1/2	4	0	0	0	0
3/8	81	5	0	0	0
1/4	15	93	53	0	0
No. 4	-	2	43	1	0
No. 8	-	-	2	24	0
No. 16	-	-	2	52	1
No. 30	-	-	-	15	35
No. 50	-	-	-	4	29
No. 100	-	-	-	2	15
Pan	-	-	-	2	20

[a] Handbook values.

Table 2. Aggregate Physical Properties

Aggregate Size (in.)	Dry Loose Unit Weight (pcf)	Dry Unit Weight of Individual Aggregate Particles (pcf)	Void Volume of Aggregate Particles (%)
1/2	40[a]	70[a]	-
3/8	44.4	84.2	54
5/16	48.9	91.7	51
Coarse Sand	55.0	104.8	47
Fine Sand	62[a]	106[a]	-

[a] Handbook value.

Table 3. Polymer Loading in Aggregate

Specific Gravity of Polymer = 1.10

Aggregate Size (in.)	Polymer Loading (% by Weight)			Percent Void Volume Empty After Second Impregnation (%)
	First Impregnation	Second Impregnation	Calculated Maximum	
1/2	29.1	38.1	-[a]	-
3/8	31.8	38.4	44.0	12.7
5/16	28.4	34.9	38.2	8.6
Coarse Sand	29.5	-[b]	31.9	7.5
Fine Sand[c]	-	-	-	-

[a] Not available.

[b] Sand was not reimpregnated.

[c] Not impregnated.

Table 4. Mix Designs

Cement: Portland Type III, High Early Strength
Water Reducer: Pozzolith 300 N at Rate of 3 oz/sack

Mix No.	Cement/Sand/ Coarse Aggregate[a] (by weight)	Cement Content (lb/yd^3)	Water/Cement (by weight)		Slump (in.)	
			Regular	PFA	Regular	PFA
1	1/2.22/1.41	460	0.33	0.58	1-1/4	1
2	1/1.55/1.12	590	0.32	0.49	2-1/4	2
3	1/1.77/0.94	710	0.31	0.44	2-1/2	2
4	1/0.78/1.21	710	0.28	0.41	2-1/2	4

[a] Proportions are for regular lightweight materials in a dry or "as received" condition from manufacturer. Material contained some moisture from environment. Aggregate sizes were blended as follows:

Sand	Parts (by weight)	Coarse Aggregate	Parts (by weight)
Coarse Sand	2	1/2 in.	3
Fine Sand	1	3/8 in.	1
		5/16 in.	1

Table 5. Test Results

Mix No.	Compressive Strength[a] (psi)			Split Tensile Strength[b] (psi)			Elastic Modulus[c] (x 10^6 psi)			Poisson's Ratio		
	Regular	PFA	%[d] Difference	Regular	PFA	% Difference	Regular	PFA	% Difference	Regular	PFA	% Difference
1	3,840 4.6[e]	4,450 3.6	+15.8	420 5.0	430 2.6	+2.3	1.78 4.4	1.78 2.0	0	0.26 16.8	0.21 0.0	-19.2
2	4,700 5.7	5,940 1.3	+26.4	470 2.3	500 3.7	+6.4	1.96 3.8	2.03 0.0	+3.6	0.25 6.0	0.27 2.1	+8.0
3	5,180 2.7	6,400 6.1	+23.6	480 5.9	500 5.0	+4.2	2.08 0.0	2.14 8.3	+2.9	0.25 11.4	0.28 12.4	+12.0
4	5,200 11.1	6,580 3.8	+26.5	500 11.2	520 5.5	+4.0	2.19 1.3	2.41 1.4	+10.0	0.24 3.6	0.22 10.3	-8.3

[a] Average of six specimens.

[b] Average of five specimens.

[c] Average of three specimens.

[d] $\% \text{ difference} = \frac{\text{PFA - Regular}}{\text{Regular}} \quad (100)$

[e] Coefficient of variation.

Table 6. Cost Data for Three Types of Concrete

Type of Concrete	Cost of Following Materials ($/yd^3)		
	Aggregate	Concrete	In-Place Concrete
Normal Weight	6	40	1,040
Regular Lightweight	25	65	1,065
Polymer-Filled Aggregate (PFA)	325	350	1,350

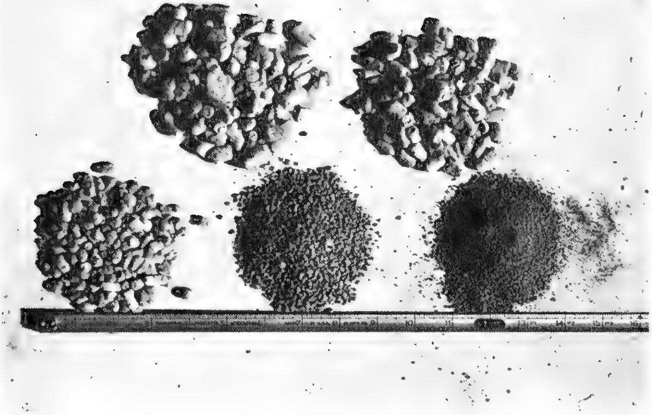


Figure 1. Regular lightweight aggregates 1/2, 3/8, and 5/16 inch in size and coarse and fine sand.

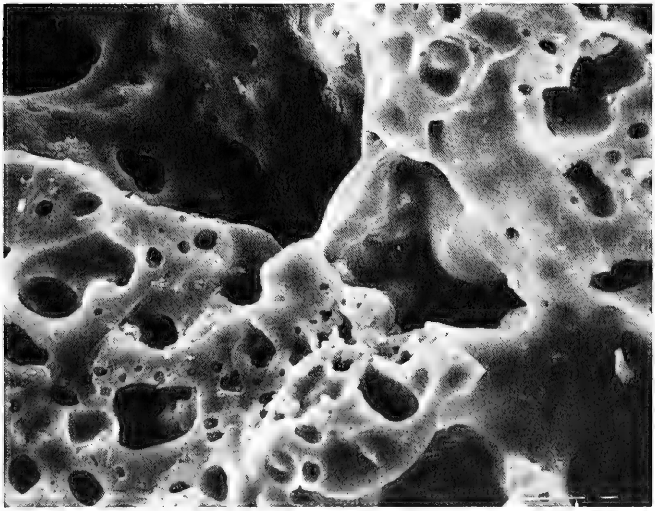


Figure 2. Internal structure of regular lightweight aggregate particle (x 600).

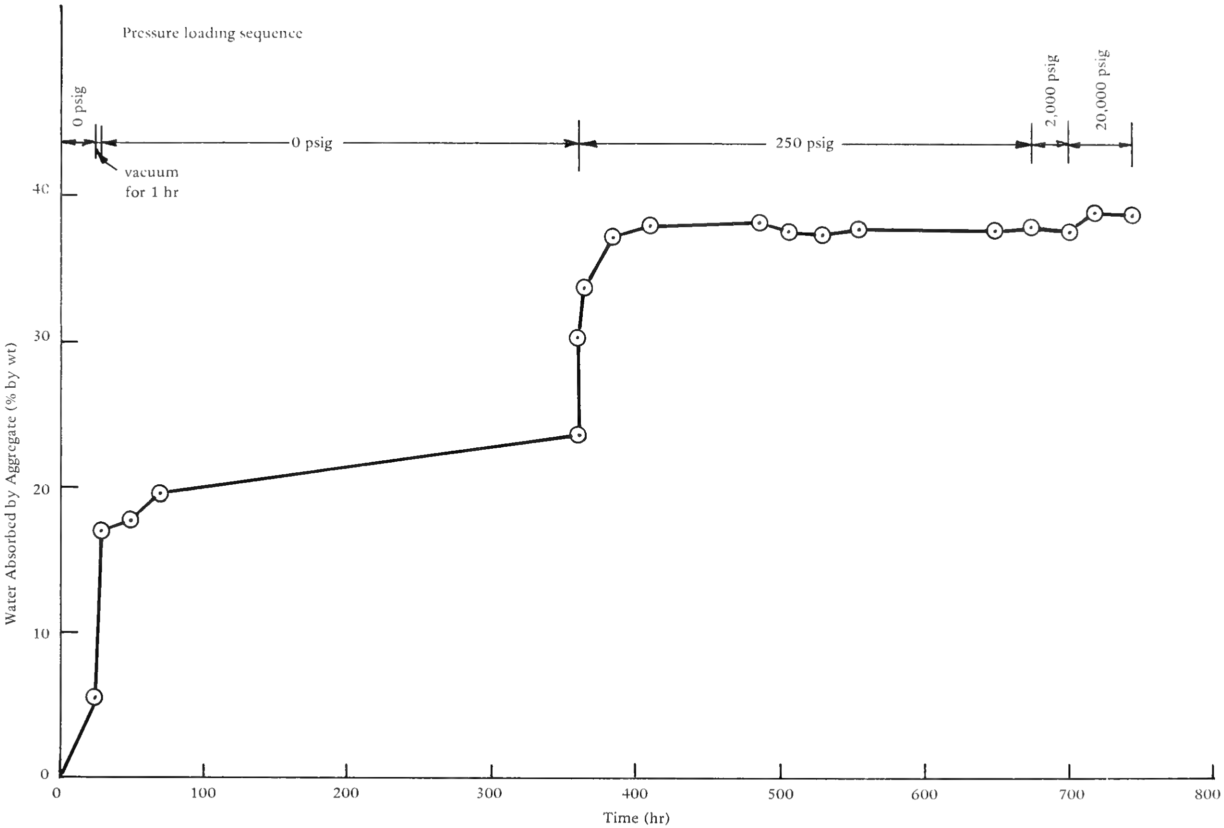
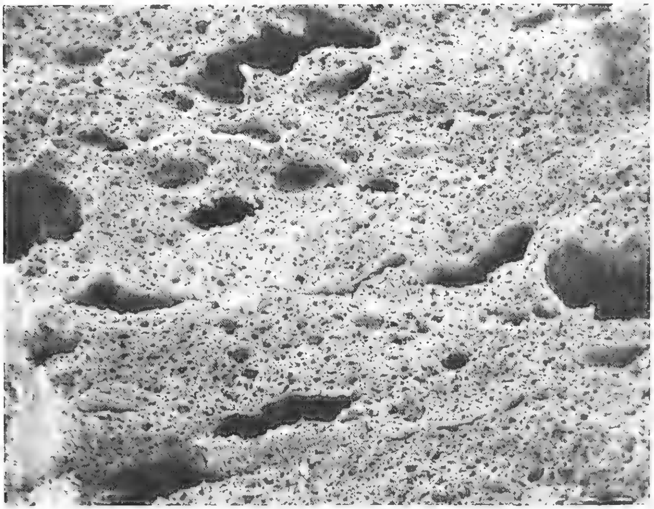


Figure 3. Water absorption behavior for 3/8-inch regular lightweight aggregate.

(a) Polymer-filled.



(b) Regular lightweight.

Figure 4. Aggregate particle at 15 times magnification.

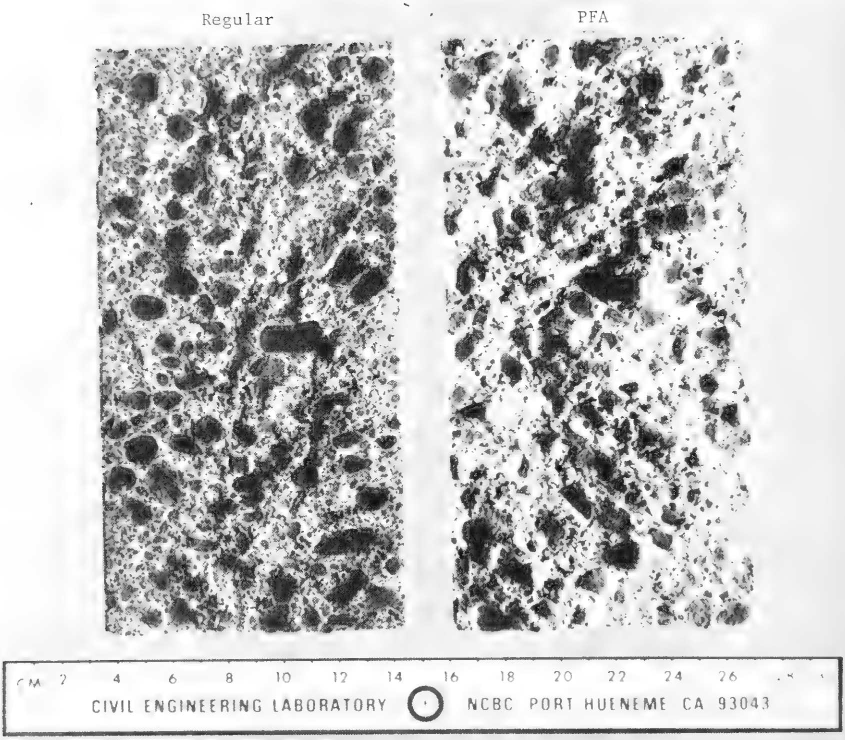


Figure 5. Sections from splitting tensile test specimens showing bond failure for PFA concrete and aggregate failure for regular lightweight concrete.

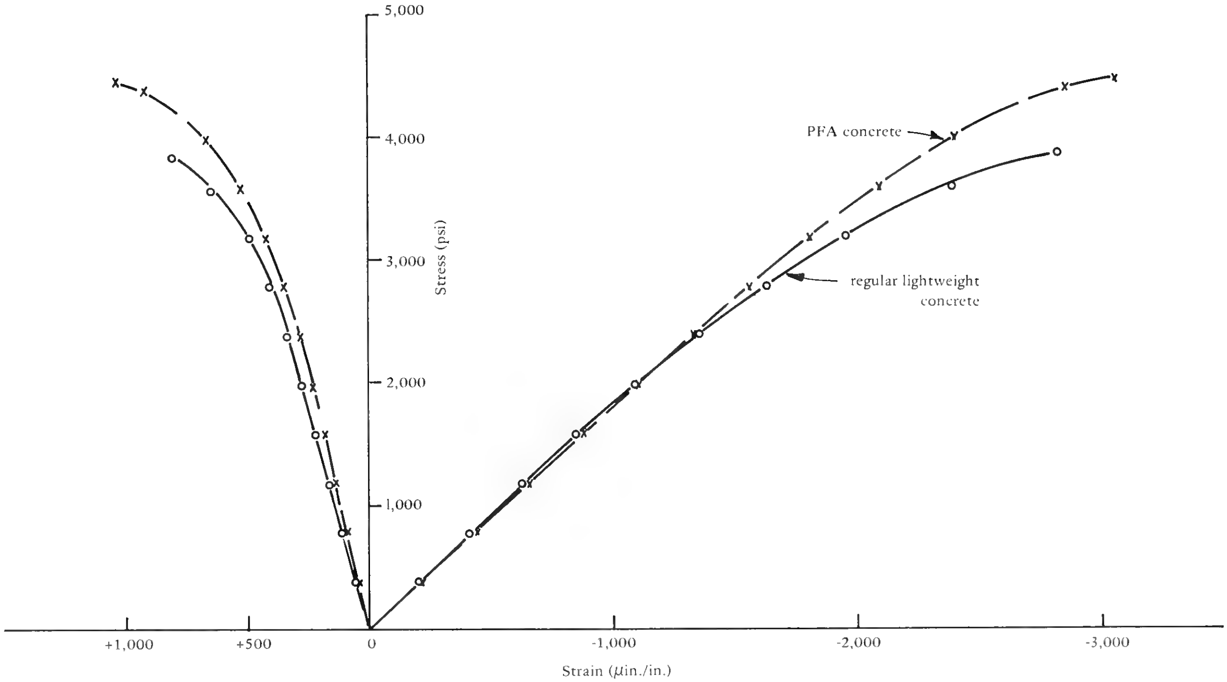


Figure 6. Stress-strain behavior for Mix no. 1 4x8-inch concrete cylinders. Each curve is the average of data from three specimens.

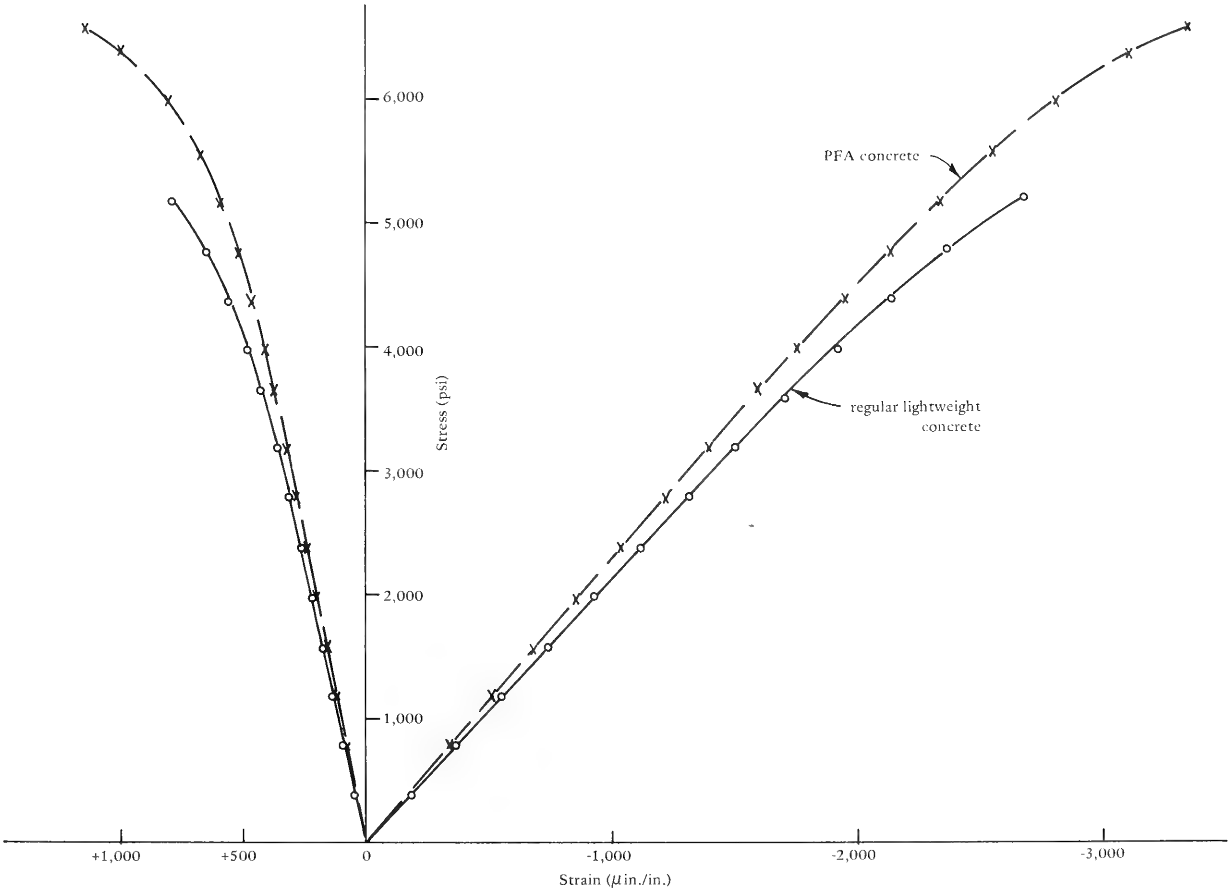


Figure 7. Stress-strain behavior for Mix no. 2 4x8-inch concrete cylinders. Each curve is the average of data from three specimens.

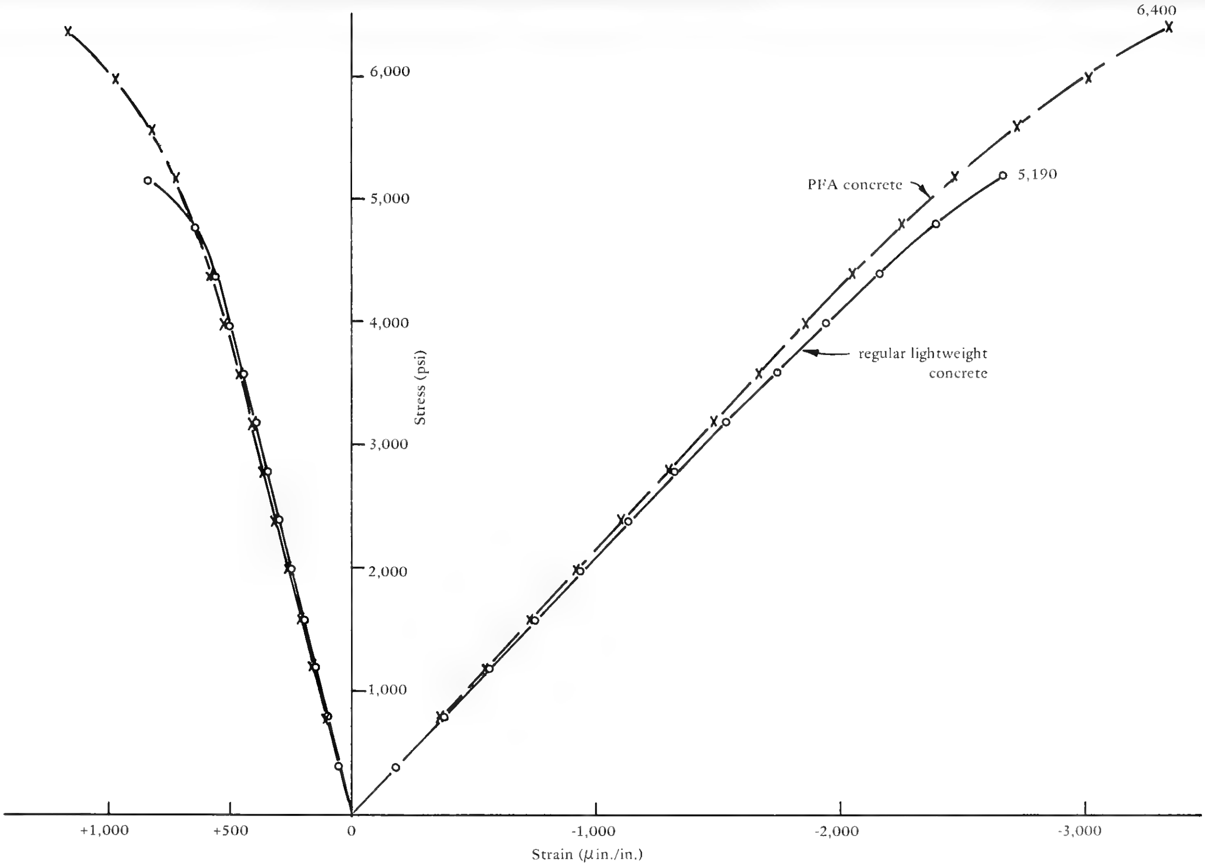


Figure 8. Stress-strain behavior for Mix no. 3 4x8-inch concrete cylinders. Each curve is the average of data from three specimens.

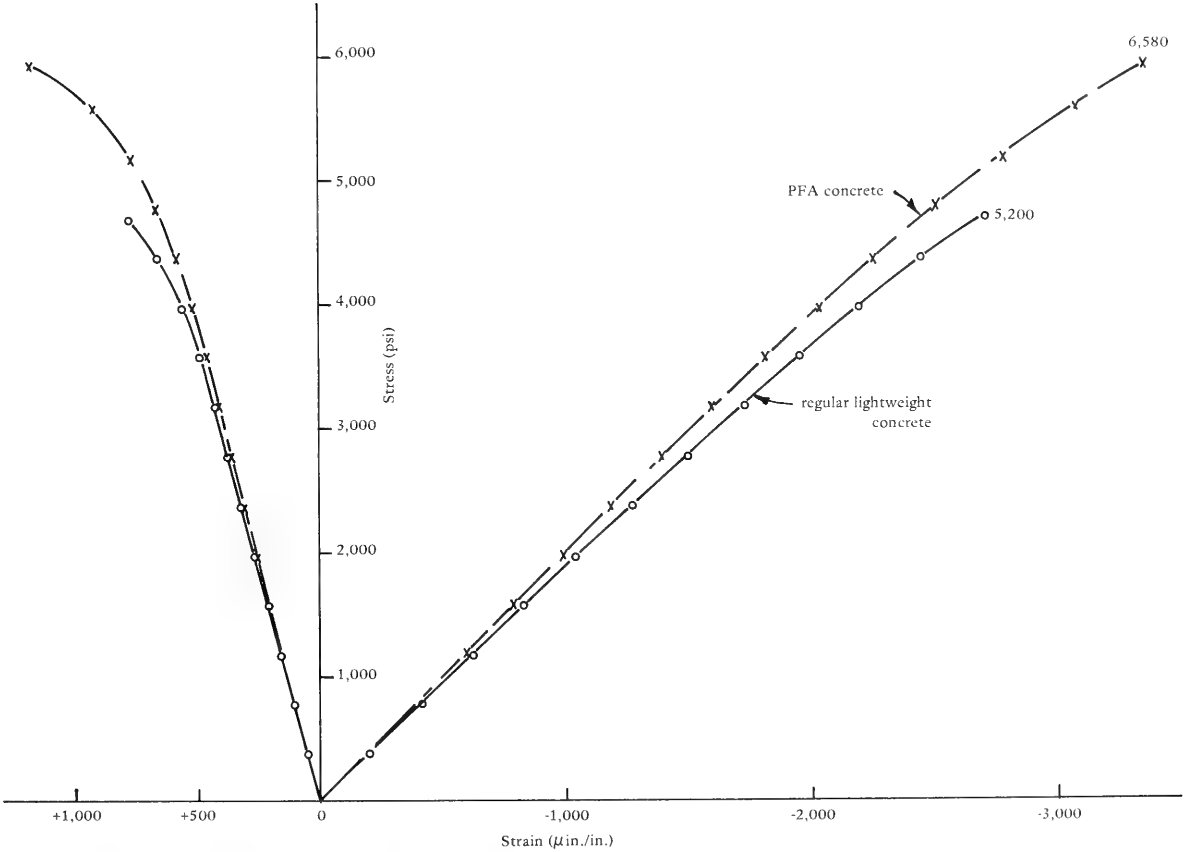


Figure 9. Stress-strain behavior for Mix no. 4 4x8-inch concrete cylinders. Each curve is the average of data from three specimens.

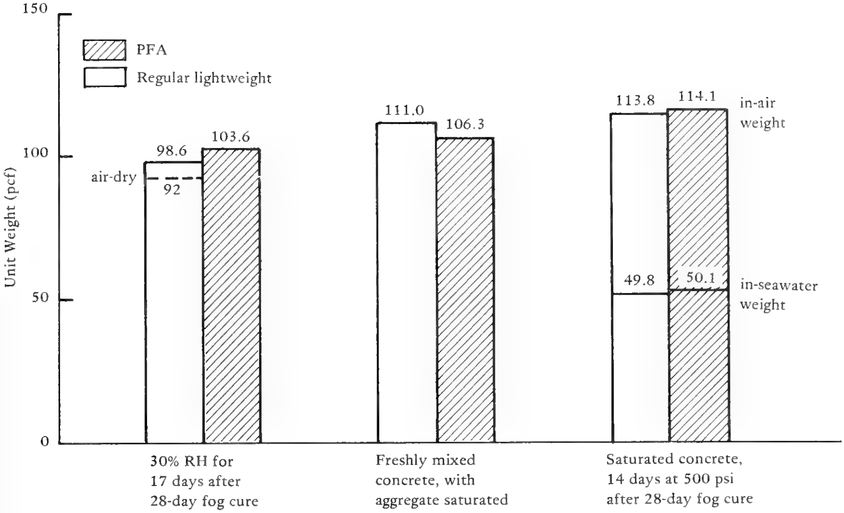


Figure 10. Comparison of unit weights for Mix no. 1 concretes.

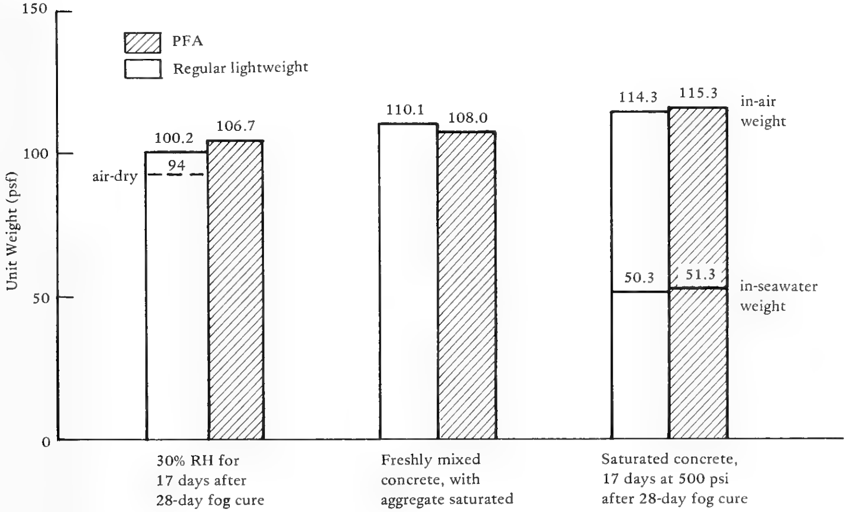


Figure 11. Comparison of unit weight for Mix no. 2 concretes.

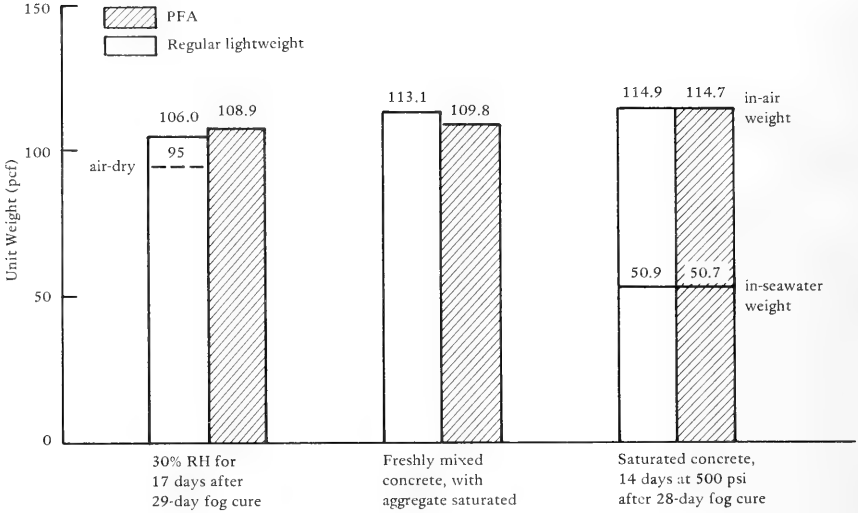


Figure 12. Comparison of unit weights for Mix no. 3 concretes.

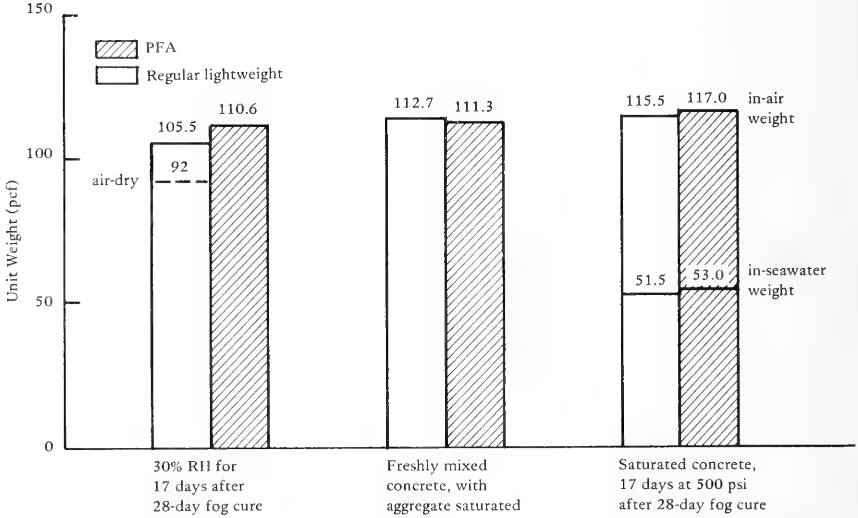


Figure 13. Comparison of unit weights for Mix no. 4 concretes.

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