Creep and Shrinkage of Lightweight Concrete

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The following report is the result of a study sponsored by Carolina Stalite Company and conducted at North Carolina State University by Michael L. Leming.

Purpose: To investigate the creep and shrinkage potential of concrete made with STALITE lightweight aggregate (ASTM C 330). Conventional strength and elastic modulus, as well as standard plastic concrete characteristics were also determined.

Concrete Mixes: Four (4) different mixes of concrete were produced and examined.

- **S-1.** A standard lightweight concrete of a type commonly used in commercial construction
- **S-2.** A commodity grade concrete similar to **S-1** except with conventional coarse aggregate (not lightweight)
- **S-3.** A mix with the same mortar fraction, paste proportions and coarse aggregate volume as **S-2**, but made with STALITE lightweight aggregate instead of conventional aggregate.
- **S-4.** A high strength lightweight concrete

Test Program: For each mix, a series of tests were conducted at the plastic and hardened stages of the concrete. First, unit weight, volumetric air content, and slump were determined. Then a series of 6" x 12" cylinders were cast to test the physical properties of the corresponding hardened concretes.

Duplicate cylinders were fabricated for determination of elastic modulus (E) and splitting tension strength ($f$ct) at 7 days and 28 days. Compressive strength (f'c) was determined by averaging the test results from two (2) specimens at 7 days. Results from three (3) specimens were used in determining compressive strength at 28 and 365 days.

Five (5) cylinders were cast with embedded brass gage points for determination of creep. Three (3) of these cylinders were loaded, and the remaining two (2) were kept as "control specimens." Additionally, three (3) rectangular prizms 4" x 4" were cast for determination of air dry shrinkage.

Conclusions: *Splitting tension strength* for all specimens at 7 and 28 days was determined to be within ACI 318 guidelines based on compressive strength. **S-1** and **S-3** showed higher splitting tension strength than is anticipated for most lightweight concretes. Splitting tension strength at one year was shown to increase very little.

The *tensile strength* of concrete is a small percentage of compressive strength in all high strength concretes. The values for **S-4**, the high strength mix using STALITE lightweight aggregate correspond very favorably to those reported by others who have investigated high strength lightweight concretes.

Values of *elastic modulus* for **S-1** and **S-3** were significantly higher than predicted by ACI equations based on compressive strength and unit weight. This is in all probability due to the fact that, compared to many other commercially available lightweight aggregates, the tested lightweight aggregate, STALITE (rotary kiln expanded slate), provides a superior stiffness. At the high strength level, again **S-4** data compare favorably to the results obtained from other tests of high strength lightweight concretes.

The *unit weights* (air dry) of **S-1** and **S-3** are well within the acceptable range for lightweight concrete for most commercial construction. The unit weight (air dry) of the high strength **S-4** is less than the maximum allowed even for conventional lightweight concrete.

The *values of creep* for the lightweight concretes are very low in comparison to national averages for all concretes.

There is no statistically significant difference in *shrinkage* between **S-1** and **S-3**, nor between **S-2** and **S-4**. The difference of approximately 20 percent in shrinkage values shown for **S-2** and **S-3** may be typical.

It is significant that the values of estimated shrinkage strain of the lightweight aggregate concretes at one year are all relatively low compared to national averages given in ACI 209. This is most likely related to the superior stiffness of the STALITE expanded slate aggregate.

Creep & Shrinkage
Laboratory Test Results

	S-1	S-2	S-3	S-4
Quantities (pcy)	Lightweight	Normal Wt.	Lightweight	Lightweight
Cement (type I)	546	560	550	536
GBFS (Grade 120)	---	---	---	342
Water	277	277	274	323
Normal Weight Aggregate				
ASTM C 33 (#67)	---	1710	---	---
STALITE Lightweight Aggregate				
ASTM C 330	900	---	950	940
Unit Weight (plastic)(pcf)	112.3	140.4	111.6	121.6
Unit Weight (dry)(pcf)	108.5	139.8	109.2	116.4
Slump (in)	4.5	4.25	4.25	6.75
Air (%)	7.8	7.0	7.1	1.5
Compressive Strength *f*'c (psi)				
7 Days	2960	3390	2900	5340
28 Days	3860	4420	3970	7180
365 Days	4540	5220	4670	8290
Splitting Tension Strength *f*ct (psi)				
7 Days	345	375	365	370
28 Days	400	405	425	495
365 Days	410	405	425	520
Elastic Modulus E (million psi)				
7 Days	2.71	3.22	2.77	3.38
28 Days	2.93	3.61	2.94	3.58
365 Days	2.97	3.85	2.99	3.84
Creep Data (at 365 days)				
Load (kips)	35	40	35	50
% 28 day *f*'c	32	32	31	25
Specific Creep	0.84	0.43	0.89	0.29
Creep Coefficient	2.6	1.7	2.7	1.2
Shrinkage Data (at 365 days)				
Microstrain	380	360	390	310

Discussion of Results: When all factors other than aggregate weight are equal, the measured slump of lightweight concrete generally will be less than that of conventional concrete at the same workability. This factor was not incorporated into the **S-3** mix. **S-2** and **S-3** had the same measured slump. This, in turn, has the effect of making the results somewhat easier to compare for the practicing engineer, although not quite as exact theoretically.

Compressive strength values were somewhat lower than anticipated. Air contents, however, were somewhat higher.

Unit weights (air day) of the standard lightweight concretes (**S-1** and **S-3**) were below 110 pcf. The unit weight of **S-4** was at the lower end of the 115 to 120 pcf range of unit weights typical of high strength lightweight concretes.

The creep coefficient shown is based on initial tangent modulus, NOT measured elastic modulus.

Specific creep of the moderate strength, lightweight concretes (**S-1** and **S-3**) is significantly higher than that of the moderate strength, conventional normal weight concrete (**S-2**). These are very typical results. Note, however, that the values for the lightweight concretes are very low compared to national averages for all concretes. This result and the high relative values of elastic modulus are related to the stiffness of the STALITE lightweight aggregate.

For **S-2** and **S-3**, which differed only in aggregate type, there appears to be only a small statistically significant difference in shrinkage. However, this analysis is based on data with large variability. Shrinkage is primarily a paste phenomenon, but restraint provided by the aggregate plays an important role. While the difference seen is typical for mixes with lightweight versus conventional coarse aggregate, it is interesting to note that the data for shrinkage, creep and elastic modulus are all consistent with an aggregate of superior stiffness.

STALITE

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