A New Look at Water, Slump, and Shrinkage

How much does a gallon of water or an inch of slump increase drying shrinkage? New data shows that small increases in water or slump have little impact.

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Owners and engineers increasingly demand low-shrinkage concrete to reduce the number of cracks, crack width, and curling. Some engineers even specify shrinkage limits for submittals of concrete proportions.

How can drying shrinkage be minimized? Much of the literature on the subject asserts that concrete water content is the most important controllable factor affecting shrinkage. Because of this, a common approach to shrinkage reduction is limiting the amount of mixing water by imposing strict limits on slump—such as a maximum design value of 3 inches—and prohibiting jobsite water additions. However, we recently conducted research showing that the addition of a small amount of water at the jobsite will have little effect on shrinkage.

Table 1. Effect on drying shrinkage of adding 1 gallon of water

Cement content (lb/yd^3)	Shrinkage per gallon, %	Average shrinkage, %	Shrinkage increase, %
470	+0.0018	0.039	4.6%
564	+0.0024	0.043	5.6%
658	+0.0031	0.046	6.7%
		Avg.	5.6%

Note: Based on Figure 1.

Why limit water content?

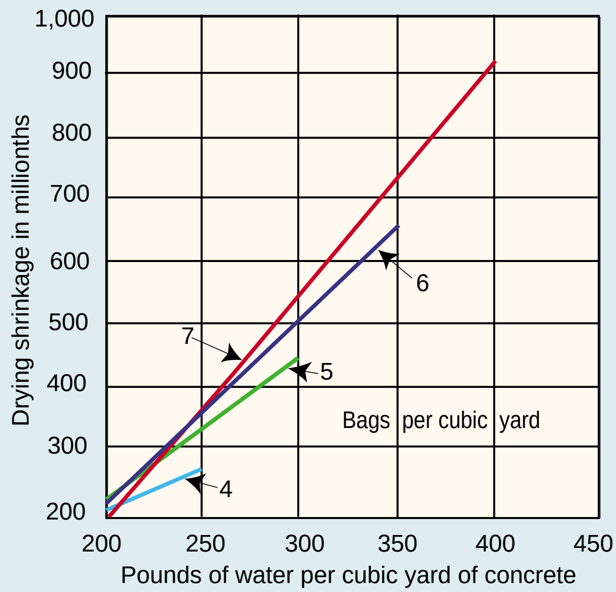
Figure 1, from the U.S. Bureau of Reclamation's *Concrete Manual* (Ref. 1), is the basis for limiting water content to control shrinkage. For most concretes, the producer selects a water content of 250 to 300 pounds per cubic yard. As shown in Figure 1, for a concrete containing 470 pounds of cement per cubic yard (5-sack mix) and no admixtures, increasing the water content from 250 to 300 pounds increases drying shrinkage by about 33%. Thus, the choice of the water content for a mix proportioned to meet shrinkage limits is important. But what's the effect of an extra gallon of water added in the field?

Based on Figure 1, Table 1 shows that adding an extra gallon of water per cubic yard increases shrinkage by about 5% for cement contents of 470 to 658 pounds per cubic yard. Work by Carlson published in 1938 (Ref. 2) shows that for each 1% increase in mixing water, concrete shrinkage increases by about 2%. For an initial water content of 275 pounds per cubic yard, this would indicate that adding a gallon of water increases shrinkage by 6%.

How reliable are the results from these two sources today? The first edition of the USBR *Concrete Manual*, also published in 1938 (Ref. 3), indicates that M.D. Lagaard of the Portland Cement Association furnished the drying-shrinkage data. It is based on tests conducted on 5x5x17-inch concrete and mortar specimens moist-cured for 7 days and then allowed to air-dry at 70° F and 50% relative humidity for 6 months. We could find no other data regarding the concrete or mortar compositions, or the numbers of each type of specimen included in the averages. We do know that PCA first started machine mixing in their laboratories in 1940 and that ASTM C 157, "Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete," was first proposed in the same year. Thus the concrete wasn't mixed or tested for shrinkage in accordance with the methods used today nor, we assume, did it contain chemical admixtures.

To analyze more current information, we teamed with Baker Concrete Construction, Monroe, Ohio, a contractor with considerable experience on projects that specify shrinkage limits, to examine the effects of slump and water content on drying shrinkage.

Figure 1. Relationship between drying shrinkage and water content (Ref. 1).



Updating the database

Since slump is the yardstick by which water-content changes usually are estimated in the field, Ross Martin of Baker Concrete and Carl Bimel, a consultant, developed a program for measuring shrinkage of concretes made with three different slumps (3, 5, and 7 inches). Because ASTM C 94, "Standard Specification for Ready-Mixed Concrete," requires that concrete be within the permissible slump range for 30 minutes, the concretes were designed to yield the target slump 30 minutes after discharge. The Type I cement content also varied (480, 560, and 640 pounds per cubic yard), as did the type of water reducer (low-, mid-, high-range, or no water reducer). Target slumps were reached by varying the water content and the type and dosage of the water reducer. All the test work was completed by Bowser Morner in its Dayton, Ohio, test lab.

Technicians used No. 57 crushed limestone and fine aggregates from the same source in all batches. They held the coarse-aggregate content constant at 1,750 pounds per cubic yard while varying the fine-aggregate content slightly to adjust for water-content changes needed to achieve the desired slump. For each mix tested, technicians made three specimens for length-change measurements in accordance with ASTM C 157. Table 2 shows mix proportions and fresh and hardened concrete properties. It also shows the average percent shrinkage at the indicated elapsed number of days following curing.

Water content vs. drying shrinkage

Figures 2 and 3 show 1-year shrinkage vs. water content for concretes with no water reducers and for concretes with and without water reducers. Figure 2 shows a slight increase in average drying shrinkage with an increase in water content. Based on a regression analysis of the data, the average drying-shrinkage increase for an added gallon of water was 2.4%—about half the shrinkage predicted by studies from the late 1930s. There was no consistent relationship between cement content and drying shrinkage.

In Figure 3, the best-fit regression line is nearly horizontal, indicating no relationship between water content and shrinkage. For the materials used in this investigation, an increase in water content, on average, didn't increase concrete shrinkage.

Slump vs. drying shrinkage

Figures 4 and 5 show 1-year shrinkage vs. slump for concretes with no water reducers and for concretes with and without water reducers.

As shown in Figure 4, average drying shrinkage increases with an

Table 2. Mix proportions, concrete properties, and shrinkage data

(For mixes with 480, 560, and 640 lb/yd^3 of portland cement)

Slump at 30 minutes	3 inches			5 inches			7 inches			
Water reducer	None	Low-range	Mid-range	None	Low-range	Mid-range	None	Low-range	Mid-range	High-range
Mix Identification #	**1**	**4**	**7**	**2**	**5**	**8**	**3**	**6**	**9**	**10**
Portland cement, lb	480	480	480	480	480	480	480	480	480	480
Coarse aggregate, lb	1,750	1,750	1,750	1,750	1,750	1,750	1,750	1,750	1,750	1,750
Fine aggregate, lb	1,530	1,540	1,550	1,510	1,520	1,530	1,490	1,500	1,510	1,530
Water, lb	278	260	262	285	277	277	305	285	292	280
Water reducer, oz/ 100 lb cement		4.0	8.0		4.0	8.0		4.0	8.0	10.0
Water-cement ratio	0.580	0.542	0.546	0.594	0.577	0.577	0.635	0.594	0.608	0.583
Fresh Concrete										
Initial slump, in.	4½	4¼	4¼	7	6¼	7	8¼	8¾	8¼	3½
Slump at 30 min, in.	3	3	2½	5½	5½	5½	7	7½	7¼	7½
Hardened Concrete										
Compressive strength, psi (28 days)	6170	6370	6140	5320	5540	6230	5210	5460	5860	5930
Shrinkage, % (standard)										
28 days	-0.034	-0.038	-0.038	-0.041	-0.047	-0.037	-0.059	-0.041	-0.038	-0.032
90 days	-0.050	-0.049	-0.053	-0.050	-0.050	-0.052	-0.068	-0.052	-0.056	-0.050
180 days	-0.052	-0.050	-0.050	-0.050	-0.052	-0.050	-0.071	-0.053	-0.055	-0.049
365 days	-0.053	-0.052	-0.051	-0.052	-0.051	-0.051	-0.070	-0.060	-0.057	-0.065

Slump at 30 minutes	3 inches			5 inches			7 inches			
Water reducer	None	Low-range	Mid-range	None	Low-range	Mid-range	None	Low-range	Mid-range	High-range
Mix Identification #	**12**	**15**	**18**	**13**	**16**	**19**	**14**	**17**	**20**	**21**
Portland cement, lb	560	560	560	560	560	560	560	560	560	560
Coarse aggregate, lb	1,750	1,750	1,750	1,750	1,750	1,750	1,750	1,750	1,750	1,750
Fine aggregate, lb	1,450	1,460	1,470	1,430	1,440	1,450	1,410	1,420	1,430	1,450
Water, lb	271	280	231	291	282	258	303	278	278	265
Water reducer, oz/ 100 lb cement		4.0	8.0		4.0	8.0		4.0	8.0	10.0
Water-cement ratio	0.484	0.500	0.413	0.520	0.504	0.461	0.541	0.496	0.496	0.473
Fresh Concrete										
Initial slump, in.	4½	4¼	4½	7	7	6¾	9	8¾	8¾	3¾
Slump at 30 min, in.	3	3	3	5½	5½	5	7½	7½	7¼	7½
Hardened Concrete										
Compressive strength, psi (28 days)	6990	7500	7560	6440	7410	7520	6120	6630	7180	7230
Shrinkage, % (standard)										
28 days	-0.030	-0.024	-0.029	-0.027	-0.029	-0.031	-0.031	-0.031	-0.030	-0.029
90 days	-0.041	-0.041	-0.040	-0.042	-0.043	-0.040	-0.046	-0.045	-0.046	-0.049
180 days	-0.040	-0.038	-0.041	-0.043	-0.041	-0.042	-0.044	-0.046	-0.047	-0.044
365 days	-0.040	-0.052	-0.049	-0.051	-0.050	-0.060	-0.044	-0.055	-0.046	-0.044

Slump at 30 minutes	3 inches			5 inches			7 inches			
Water reducer	None	Low-range	Mid-range	None	Low-range	Mid-range	None	Low-range	Mid-range	High-range
Mix Identification #	**23**	**26**	**29**	**24**	**27**	**30**	**25**	**28**	**31**	**32**
Portland cement, lb	640	640	640	640	640	640	640	640	640	640
Coarse aggregate, lb	1,750	1,750	1,750	1,750	1,750	1,750	1,750	1,750	1,750	1,750
Fine aggregate, lb	1,360	1,370	1,380	1,340	1,350	1,360	1,320	1,330	1,340	1,360
Water, lb	278	258	257	291	278	274	301	303	288	265
Water reducer, oz/ 100 lb cement		4.0	8.0		4.0	8.0		4.0	8.0	10.0
Water-cement ratio	0.435	0.403	0.402	0.454	0.434	0.428	0.471	0.474	0.450	0.414
Fresh Concrete										
Initial slump, in.	4¾	4½	4¾	6½	7¼	7¼	8½	8½	8¾	3½
Slump at 30 min, in.	3¼	3	3¼	5	5	5½	7¼	7½	7¼	7½
Hardened Concrete										
Compressive strength, psi (28 days)	7850	8400	8560	7810	7990	8060	7280	7790	7830	7050
Shrinkage, % (standard)										
28 days	-0.019	-0.033	-0.031	-0.028	-0.026	-0.032	-0.030	-0.029	-0.041	-0.028
90 days	-0.038	-0.044	-0.042	-0.051	-0.039	-0.044	-0.053	-0.043	-0.055	-0.043
180 days	-0.036	-0.047	-0.044	-0.046	-0.038	-0.045	-0.048	-0.044	-0.055	-0.047
365 days	-0.035	-0.048	-0.038	-0.046	-0.037	-0.039	-0.047	-0.043	-0.048	-0.045

Note: The shrinkage data for mix 3 was treated as an outlier and is not included in Figures 2, 3, 4, and 5.

increase in slump. A regression analysis indicates about a 5% increase in drying shrinkage for each 2-inch increase in slump. As a general rule of thumb, each added gallon of water per cubic yard increases slump by 1 inch. This agrees with results of the regression analysis from Figure 2, indicating that 1 gallon of water increases drying shrinkage by about 2.4%. The results also match results of tests by another investigator (see "Slump and Shrinkage").

Figure 5 shows a slight increase in drying shrinkage with increased slump. The average drying shrinkage increase for a 2-inch increase in slump is about 4%.

Effects of jobsite water additions

With proper inspection, jobsite water additions seldom exceed 2 gallons of water per cubic yard of concrete, or enough to increase the slump 2 inches. Based on data from this study, those 2 gallons of water, or extra 2 inches of slump, might increase drying shrinkage by 4% to 5%. If the expected drying shrinkage before water addition was 0.05%, the extra 2 gallons would then increase this by 0.0025% for a total shrinkage of 0.0525%. How significant is this increase? According to the precision and bias statement in ASTM C 157, the standard deviation of the mean of three air-dried shrinkage specimens is 0.0048%. So based on testing variability alone, with no water additions, we

Figure 2. Effect of water content on 1-year drying shrinkage for concretes with no water reducers.

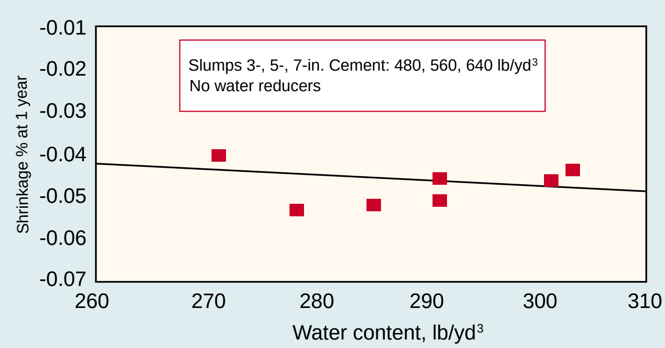
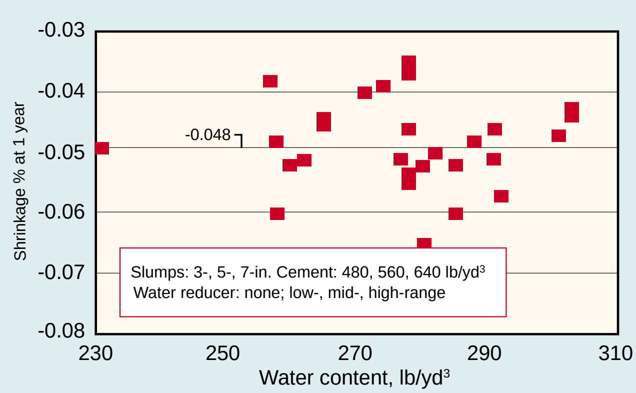


Figure 3. Effect of water content on 1-year drying shrinkage for concretes with and without water reducers.



Slump and shrinkage

If increasing slump by a few inches doesn't affect drying shrinkage, why do so many people believe it does? Two of the most commonly cited references asserting that increasing slump increases shrinkage are a paper by Tremper and Spellman (Ref. 1) and an American Concrete Institute report (Ref. 2). Neither reference presents original shrinkage data to substantiate the assertion.

The ACI 224 report plots required water content vs. maximum aggregate size for 1- to 2-inch and 3- to 4-inch-slump concretes based on approximate mixing water requirements for these slumps and aggregate sizes drawn from a table used to proportion concrete (Ref. 3). The table indicates that it takes a 30-pound increase in water content to increase slump about 2 inches. The ACI 224 report also includes the USBR shrinkage curve for a 7-sack (656-pound-per-cubic-yard) concrete (Fig. 1) to illustrate the drying-shrinkage reduction (about 11%) that would result from a 2-inch slump reduction.

Tremper and Spellman also used the USBR shrinkage curve and assumed a cement factor of 6 sacks per cubic yard. Using a similar table from an earlier ACI proportioning guide, they showed that increasing slump from 3 to 4 inches to 6 to 7 inches requires a 17-pound-per-cubic-yard increase in water content. They concluded the equivalent increase in shrinkage is 10%.

Meininger (Ref. 4) provided shrinkage data for concretes with different slumps as summarized in the tables below. The first data set shows a 4% shrinkage increase when slump increased by 4 inches. The second data set shows a 6½% shrinkage increase when slump increased by 2 inches. These shrinkage increases are significantly lower than the previously cited increases.

References

1. Bailey Tremper and D.L. Spellman, "Shrinkage of Concrete—Comparison of Laboratory and Field Experience," *Highway Research Record No. 3*, Highway Research Board, 1963.

2. ACI 224R-90, "Control of Cracking in Concrete Structures," American Concrete Institute, Farmington Hills, Mich., 1990, p. 12.

3. ACI 211.1, "Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete," ACI, 1989.

4. R.C. Meininger, "Drying Shrinkage of Concrete," Engineering Report No. RK3, National Sand and Gravel Association and National Ready Mixed Concrete Association, 1966.

Drying shrinkage % at 6 months vs. slump

Cement content	Aggregate sample	Slump 2 to 3 in.	Slump 6 to 7 in.	Shrinkage difference	Shrinkage increase
5½ sacks	#1	0.120	0.122	+0.002	1.7%
7½ sacks	#1	0.127	0.130	+0.003	2.4%
5½ sacks	#2	0.056	0.060	+0.004	7.1%
7½ sacks	#2	0.057	0.060	+0.003	5.3%
			Avg.	+0.003	4.1%

Drying shrinkage % at 3 months vs. slump

Cement content	Aggregate sample	Slump 1 to 2 in.	Slump 3 to 4 in.	Shrinkage difference	Shrinkage increase
6 sacks	#a	0.058	0.059	+0.001	1.7%
6 sacks	#b	0.056	0.061	+0.005	8.9%
6 sacks	#c	0.046	0.053	+0.007	15.2%
6 sacks	#d	0.051	0.051	+0.000	0.0%
			Avg.	+0.003	6.5%

Notes: 3x4x16-inch prisms dried at about 70° F and 50% relative humidity
1 sack of cement = 94 pounds

Figure 4. Effect of slump on 1-year drying shrinkage for concretes with no water reducers.

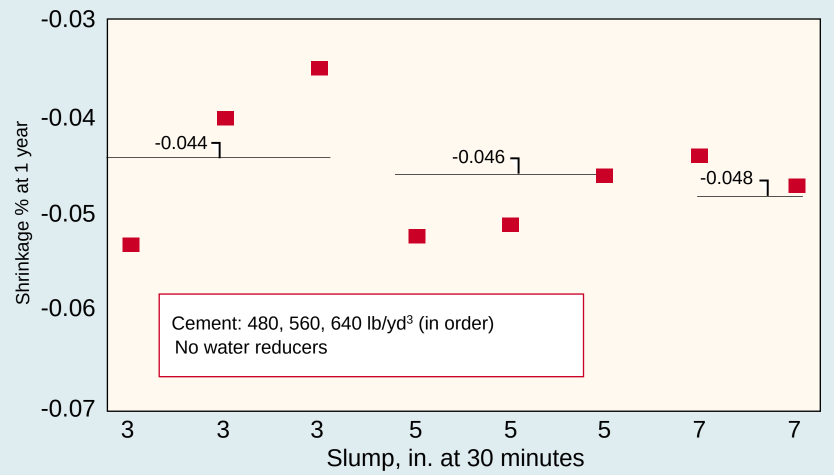
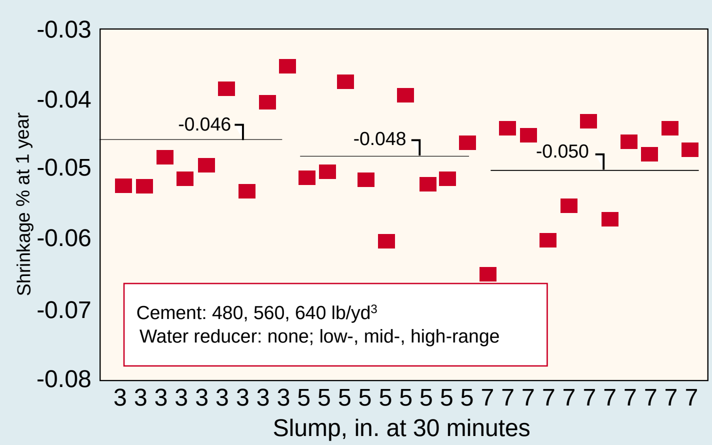


Figure 5. Effect of slump on 1-year drying shrinkage for concretes with and without water reducers.



could expect about a 3 in 10 chance that shrinkage would equal or exceed 0.0525%. Based on this probability, it appears that the amount of water the contractor can usually add in the field doesn't significantly increase drying shrinkage.

We've been conditioned to believe jobsite-added water significantly increases drying shrinkage. Based on the data presented here, that's not true if the water addition is 2 gallons or less per cubic yard. The shrinkage potential of the delivered concrete isn't going to be changed by the contractor's field practices. ■

References

1. *Concrete Manual*, U.S. Department of the Interior, Bureau of Reclamation, Eighth Edition, 1981.

2. Roy W. Carlson, "Drying Shrinkage of Concrete as Affected by Many Factors," *Proceedings: Forty-First Annual Meeting*, American Society for Testing and Materials, Vol. 38, Part II, Technical Papers, 1938.

3. *Concrete Manual*, U.S. Department of Interior, Bureau of Reclamation, First Edition, 1938.