Understanding ASTM C 94

Answers to commonly asked questions about specifying ready mixed concrete

By Richard D. Gaynor

ASTM C 94 "Standard Specification for Ready Mixed Concrete" is the specification almost universally used in the United States for concrete manufactured and delivered to a purchaser in a freshly mixed and unhardened state. Two other specifications occasionally used are ASTM C 685 "Specification for Concrete Made by Volumetric Batching and Continuous Mixing" and AASHTO M-157, with the same title as C 94. Naturally, C 685 applies to concrete made in mobile batcher mixers and is used generally for small jobs or under special circumstances. AASHTO M 157 is modeled after C 94, but deviates from it in areas where state highway departments have special concerns.

Does C 94 apply to all ready mixed concrete?

For almost any job, ASTM C 94 addresses the separate and joint responsibilities of various parties that include the contractor, concrete supplier, testing and inspection agency, specifier, and even the owner. In the simplest situation the ready mixed concrete producer will incorporate a reference to C 94 in the delivery ticket for concrete supplied to an owner or concrete finishing contractor. In commercial construction, the ready mixed concrete producer is not a part of the basic contract between the owner and a general contractor, but has a contract with the concrete subcontractor.

The catch is that C 94 clearly states that when the purchaser's requirements differ from those of C 94, the purchaser's requirements shall govern. This means that all sections of ASTM C 94 may not apply to all ready mixed concrete. It also means, as a practical matter, that the ready mixed concrete producer must be familiar with requirements of the local building code and must carefully review the job specifications before bidding.

What ordering information is needed?

The section of C 94 on ordering information requires the purchaser to specify such basic information as aggregate size, slump, and air content and to provide options for a prescription to be filled or a performance option to be met where the concrete producer proportions the mix to produce the required strength. Three specific options are described in C 94:

- Option A is the performance format where the purchaser specifies strength and the producer selects proportions of ingredients.
- Option B is the prescription format where the purchaser specifies cement content, maximum water content, and admixtures.
- Option C is a mixed format where the purchaser specifies minimum cement content, required strength, and admixtures, if required.

However, these options are rarely followed as outlined in C 94. Specifications for commercial work and work by government agencies include specific requirements that take precedence over those of C 94. In part, this is why silica fume, corrosion inhibiting admixtures, expansive cement, and even the relatively new ASTM C 1157, "Standard Performance Specification for Blended Hydraulic Cement" are not specifically permitted under C 94. That is, they can be used if specified or permitted by the purchaser.

Can a maximum water-cement ratio be specified?

A maximum water-cement ratio (w/c) or water-cementitious materials ratio (w/cm) can be specified, but C 94 doesn't contain provisions for doing this directly. Option B of the "Ordering Information" section requires the purchaser to specify both maximum water content and minimum cement content, but this focuses attention on local aggregates and the large effect they have

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The principal difficulty with specifying a maximum w/c or w/cm is that water content is difficult to measure, record, or calculate accurately. Aggregate moisture contents vary and often can't be measured with the accuracy required. Also, the water required to produce the required slump will vary depending on inevitable variations in delivery time caused by traffic and delays on the job. Additionally, specifiers are rarely prepared to define how a w/c or w/cm specification will be enforced or checked. There is no standard method that can be understood and accepted by both parties.

A part of the difficulty of determining the amount of water batched is keeping track of the water in the truck tank since that water is routinely used at the plant to do a last minute cleanup or on the job by the contractor to dampen the subgrade or clean spatter off a concrete pump. These are not operations that can be easily monitored by a jobsite inspector and, if monitoring is attempted, it can disrupt the production schedule.

Specifying an absolute maximum w/c (or w/cm) is also impractical, just as it's impractical to specify an absolute minimum strength. To ensure that no w/c falls above the specified maximum, the average w/c must be significantly lower than the specified maximum, thus requiring excessively high cement contents (see box).

Until there is a standard method of determining water-cement ratio, one of the simplest methods of assuring compliance is to rely on highly standardized strength and air content tests to ensure durability. This is particularly attractive if you believe, as I do, that strength is a better index of durability than w/c. If the user is a believer in w/c as an index of durability, then the strength specified must be consistent with the w/c desired, because strength will be checked and w/c rarely is checked. Trial batches can be used to confirm the strength level selected and the corresponding w/c.

What are the allowable slump tolerances?

If the specification gives a maximum slump of 3 inches or less, the plus tolerance is zero and the minus tolerance is 1½ inches. For a specified 3-inch-maximum slump, the concrete slump as delivered would have to fall between 1½ and 3 inches. If the specified maximum slump is greater than 3 inches, the plus tolerance is still zero and the minus tolerance is 2½ inches. For a 5-inch-maximum, the concrete slump as delivered would have to fall between 2½ and 5 inches.

As a practical matter, these permitted slump variations aren't acceptable for some jobs, such as floors with tight flatness tolerances. Tighter slump control is needed for concrete supplied for use on superflat or very flat floors because variable slump makes it difficult for finishers to produce required flatness results.

When project specifications simply give a single number for specified nominal slump, a sliding tolerance scale applies as shown in Table 1. From the table, if the specified slump were 5 inches, the permitted range would be 3½ to 6½ inches. This range would also be unacceptable for some applications such as flat floors.

Can water be added on the job?

ASTM C 94 recognizes that concrete loses slump with the passage of time, and that with traffic and other delays, it's necessary to complete mixing and to make slump adjustments on the job. A one-time addition of water is permitted in C 94, on arrival at the job, but at no later time. The maximum water content or water-cement ratio must not be exceeded. The one-time addition should not be taken too literally since the mixer driver may need to make several small additions over a short period to avoid exceeding the maximum slump.

The producer is responsible for providing concrete with a slump that stays within permissible tolerances for a period of 30 minutes, starting either on arrival at the job or after the water addition on the job, whichever is later. The use of high-range water-reducers (HRWR) complicates the control of slump if the specifier requires slump tests both before and after the HRWR addition. Although it may slow delivery, specifying slump only before HRWR addition will improve the process if facilities and space are available at either the plant or the job to make the HRWR addition.

Addition of the HRWR at the plant and relying on recordation of the amount batched is preferred and a much simpler process. The high-range water-reducers used today are much less susceptible to rapid slump loss than those available 10 or 15 years ago, and jobsite addition is rarely necessary, although some specifiers seem to have persistent memories.

What are the tolerances on air content?

The delivery tolerance on air content is ± 1.5% air. Control of air content at specified values above 5% or 6% is still difficult for most concrete producers. In the northern half of the country, state highway agencies have significantly increased the frequency of testing for air and this greatly improves control.

Over the years, a number of problems have surfaced in the control and measurement of air content. Over 15 years ago, Meininger reported tests indicating that some fly ashes contain carbon that absorbs air-entraining admixture as the concrete is mixed. This can lead to a progressive and sometimes dramatic loss of air with time. As a result, the permissible limit on fly ash loss of ignition (LOI) has been reduced to 6% or even less. The conversion of power plants to low NOX burners and a shortage of low LOI fly ash promises to increase the potential for problems in control-

Needed: A reasonable approach to maximum w/c

Even if it were possible to accurately measure the water-cement ratio of fresh or hardened concrete, caution is required in specifying w/c. Specifying an absolute maximum water-cement-ratio requires unreasonably high cement contents because a very low average or targeted w/c is needed to ensure that no w/c exceeds the specified maximum w/c.

A number of statistical criteria, similar to those used for strength test results, have been suggested as alternatives to specifying an absolute maximum w/c. With these approaches, the required difference between specified and targeted w/c depends on (1) the permitted probability of w/c exceeding a specified value and (2) the variability in w/c as indicated by standard deviation. In our experience on well-controlled jobs, the standard deviation of w/c for ready mixed concrete is about 0.02 to 0.03. Based on these values and three different probabilities of exceeding the specified w/c, the table below compares the required difference between specified and targeted value for w/c.

Required differences between targeted and specified w/c for three methods of specifying w/c

Specification for water-cementitious ratio	Standard deviation 0.02	0.025	0.03
1. One in 100 over specified w/c	0.05	0.06	0.07
2. One in 10 over specified w/c	0.03	0.03	0.04
3. One in 100 more than 0.05 over specified w/c	0.00	0.01	0.02

Line 1 shows the required difference if the w/c of only one batch in 100 is allowed to exceed the specified value. For a specified w/c of 0.40, a producer would have to supply concrete with an average w/c of 0.33 to 0.35, depending on the producer's standard deviation. For concrete containing 300 pounds of water per cubic yard, this would require using about 100 to 150 extra pounds of cement per cubic yard to ensure that the specified w/c wasn't exceeded. Besides raising concrete cost significantly, this would also result in possible performance problems such as excessive temperature rise related to the extremely high cement contents (more than 900 pounds per cubic yard for a w/c of 0.33).

Line 2 shows what happens if the specifier accepts one test in 10 above the specified w/c. Note that for a specified w/c of 0.4, this approach requires an average w/c of 0.36 to 0.37. For a water content of 300 pounds per cubic yard, this would require using about 60 to 85 extra pounds of cement per cubic yard.

Line 3 shows a different statistical approach. It would set a maximum w/c that's 0.05 above the specified value. Depending on the standard deviation, the producer would have to target an average w/c at or slightly below the specified value. For a specified w/c of 0.4, the required average w/c is 0.38 to 0.40. With this option, the amount of extra cement ranges from 0 to 40 pounds per cubic yard for concrete containing 300 pounds of mixing water per cubic yard. Yet it still provides a low probability that w/c will exceed a reasonably low value of 0.45.

The above examples with a w/c of 0.40 and a high water content tend to emphasize the impact of w/c ratio specifications on cement content. Admixtures are already being used in most concrete and such specifications would increase the use of both admixtures and pozzolans. Despite this, the fact remains that statistically based requirements that allow a reasonable probability of a w/c exceeding a specified value are the only practical way to specify w/c without requiring ridiculously low target values. However, until there's a reliable method for measuring w/c, there's no way to enforce a w/c specification. I believe that specifying and carefully measuring compressive strength is the acceptable alternative.

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ling air content.

Measured air content may also be affected by the measurement method. There have been a number of studies designed to determine if ASTM C 23l pressure air meters really work. My view is that they give the correct value if they are frequently calibrated and tests are made by knowledgeable technicians. Otherwise, the equipment and procedures can produce erratic results. ACI Grade I Field Testing Technician Certification will help to produce more reliable results.

Another issue is the loss of air in pumping. In normal pumping, air losses are rarely more than 0.5% to 1%. However, when boom pumps discharge near the pump with long sections of near vertical pipe, half or more of the air can be lost. This means that routine tests need to be made from truck discharge into the pump and from the pump when the boom is at its most vertical job position. Since the loss is either from a vacuum created as concrete slides down the near vertical line and/or from impact of the concrete with the elbows at pump swivel points, the solution is to restrict pump discharge to keep the down line full. A number of devices have been used. One or two sections of rubber hose laying on the deck or a cable arrangement that bends the end of the rubber hose into the shape of the letter “j” have both produced good results. Neither is practical in wall or column pours, but tight control of air is rarely critical to durability in walls and columns other than those that retain water. When mixes tend to lose air, the best solution is to try to place the pump so the boom configuration avoids long downward sloping sections of line.

Blistering and delamination in flatwork are other problems related to control of air content. Entrained air greatly increases the occurrence of blisters and also delaminations in steel-trowelled concrete and concrete where a dry shake is applied. Most problems seem to occur on industrial floors that are struck off with vibrating screeds and power trowelled. Although a number of factors may contribute to blistering problems, the air content should not exceed 3% or 4%.

Everyone samples the first concrete discharged. When is C 94 going to change?

ASTM C 94 references the ASTM sampling method, C 172 which requires compositing two or more portions during discharge of the middle portion of the batch. In practice, the tendency is to check air content and slump by sampling from the first cubic yard discharged. Ideally, strength specimens would be made later using a sample from the middle of the load. This is rarely done because C 94 requires air and slump tests on this sample also. Thus slump and air tests and test cylinders are often all made using concrete that’s discharged first.

I believe the sampling procedure will be changed to permit sampling anywhere in the load except the first or last couple of cubic feet. I would be comfortable with such a change because I believe mixing uniformity has improved with improvements in batching sequence at the plant.

One other change needed in the C 172 sampling procedure is to require that the sample be taken by swinging the chute and catching the full discharge stream without stopping and starting discharge from the truck. This is important with flowing concretes with slumps over about 5 or 6 inches but may not be necessary at lower slump levels.

Can the purchaser reject a load?

If the measured slump or air content falls outside specified limits, ASTM C 94 requires a retest before a load is rejected. In some

Table 1. Tolerances for nominal slumps

For specified slump of:	Tolerance
2 inches and less	± ½ inch
More than 2 through 4 inches	± 1 inch
More than 4 inches	± 1½ inch

cases, acceptable concrete may be rejected because incorrect testing methods were used by poorly trained technicians. In an ideal world, all tests would be conducted by technicians with ACI or equivalent certification. Minimum qualifications for technicians could then be agreed upon in a prejob or partnering conference before disputes about validity of test results occurred on the job.

Concrete may also be rejected because of low cylinder breaks. Here again, incorrect methods used in making, curing, and testing the cylinders may cause low breaks. ASTM is considering adding a note to C 94 to say that nonstandard moisture and temperature conditions for curing cylinders may produce low strength test results and invalidate their use as a basis for rejection. An interesting question is then whether the alternative is drilling cores—or whether it means that the invalid tests demonstrate that cores are not necessary. I suppose there is no perfect solution, but hopefully, if accepted by ASTM, the note will encourage proper testing procedures. ✣

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