

Understanding Minimum Specified Compressive Strength (f'_c)

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I have always said concrete strength is overrated. Compressive strength is only one characteristic of concrete that does not seem well understood by all. Project specifications are always specified with some minimum compressive strength requirement with the notation, f'_c . If you have read my "[Durability Position](#)" paper, I state the minimum required compressive strength (f'_c) for exterior concrete in freeze thaw environments, in moist conditions that are subject to deicers, is 4500 psi. This is what I have read in ACI documents and we NEVER disagree with the American Concrete Institute. Well, I am jumping ship. **I do not agree with specifying $f'_c = 4500$, for exterior pavements.** You may think this paper is over analyzing compressive strength of concrete, but I think it is important to understand what concrete strength data is telling us.

One key factor to durability of exterior concrete is reducing permeability. If you can reduce the permeability, then you can reduce the amount of moisture and chemicals concrete can absorb. There are many ways to reduce permeability of concrete. The most economical way is reducing the water / cement ratio. According to ACI 318 and ACI 332, the maximum water cement ratio is specified is 0.45. These documents also refer to a minimum strength requirement (f'_c) of 4500 psi.

ACI 318-08 commentary, explains in detail:

"R4.1.1....Because it is difficult to accurately determine the w/cm of the concrete, the compressive strength specified should be reasonably consistent with the w/cm required for durability. Selection of an f'_c that is consistent with the maximum permitted w/cm for durability will help ensure that the maximum w/cm is not exceeded in the field. For example, a maximum w/cm of 0.45 and f'_c of 3000 psi should not be specified for the same concrete mixture. Because the usual emphasis during inspection is on concrete compressive strength, test results substantially higher than the specified compressive strength may lead to a lack of concern for quality and could result in production and delivery of concrete that exceeds the maximum w/cm ratio."

I agree with the statement from ACI 318. I also agree that if the concrete is going to be classified as structural, $f'_c = 4500$ psi would be fine. Not only should structural buildings be designed for durability, but also for safety and public welfare, using safety factors and overdesign calculations. I also agree that if a mix that is placed has a w/c of 0.45 or less, you should see compressive strengths at 4500 psi or above. Notice I did not say "minimum *required* compressive strength (f'_c)". **What I do not agree with is specifying f'_c of 4500 psi as a requirement for non-structural exterior concrete.** ACI 332-08 "Code Requirements for Residential Concrete" also requires f'_c to be 4500 psi, as well as, maximum w/c 0.45 for exterior patios, driveways, and sidewalks. If I am going to disagree with ACI, I better have a good reason, which is the purpose for this paper.

First lets explain what minimum compressive strength (f'_c) really means. According to ASTM C 94,

- 18.4.1 The **average** of any three consecutive strength tests shall be **equal to, or greater than, the specified strength, f'_c and**

- 18.4.2 When the specified strength is 5000 psi or less, no individual strength test (average of two cylinder tests) shall be more than 500 psi below the specified strength, f'_c

Let's say a project is specified with f'_c , minimum required compressive strength of 4500 psi with a maximum water cement ratio of 0.45. A concrete subcontractor submits the project specifications to the Ready Mix Concrete producer. These requirements forces concrete producers to use equations;

- $f'_{cr} = f'_c + 1.34s$ (for mixes with 30 or more test data) or
 - $f'_{cr} = f'_c + 1200$ (for mixes with no test data history)
- Where f'_{cr} is the **average compressive strength**

If f'_c is 4500 psi and using a standard deviation (s) of 500 psi, **this will require minimum average compressive strengths, f'_{cr} , of 5170 psi to 5700 psi.** These overdesign calculations will lead to richer mixes (higher cement contents) that are not needed, or lower w/c around .40, which is not constructible for many concrete markets.

If the critical component is water cement ratio, and 0.45 is the maximum requirement, shouldn't we specify average compressive strengths, f'_{cr} ? Wouldn't that be a better way of ensuring the concrete was placed with the proper water cement ratio? What if we specified an **average strength, f'_{cr} , of 4500 psi?**

- 4500 psi = $f'_c + 1.34(500 \text{ psi})$, then Minimum Compressive Strength, $f'_c = 3830$ psi or round up to $f'_c = 4000$ psi.
- 4500 psi = $f'_c + 1200$ psi, then Minimum Compressive Strength, $f'_c = 3300$ psi or round up to $f'_c = 3500$ psi.

If I was an engineer responsible for durable concrete for my project, I would specify:

- Minimum 28-day Compressive Strength, $f'_c = 3500$ psi
 - This keeps mix designs submitted to moderate cement content, typically 3500 psi concrete has 564 lbs of cement. The higher the specified strength the more cement is added.
- Maximum water cement ratio = 0.45
 - If the specification has a maximum w/c of 0.45, you should see 28 day strengths averaging 4500 psi. Half of the tests will be below 4500 and half will be above 4500 psi, indicating that the producer and contractor supplied and placed concrete with a w/c around 0.45. Through test data I have seen, 4500 psi can be achieved with 3500 pound concrete with a w/c of 0.45. Look at the mix data sheets submitted for the project.

These do not take into account proper finishing and proper curing, which also influence surface durability. Back to my statement, concrete compressive strength is overrated. It is overrated if you don't understand what the ultimate goal for exterior concrete is...**reduce the permeability.** Compressive strength data can be a great tool to understand what is actually being placed in the field regarding water cement ratio. Technology will soon bring us equipment to test for total water content in the field by effective and efficient manners. But until then, look for test data on your project that **averages 4500 psi**