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Tests on Fresh Concrete

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Overview

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Concrete is one of the most common construction materials and consists of two phases: the mortar phase, comprised of concrete, water and air, and the aggregate phase, comprised of coarse and fine aggregates. There are two key considerations when designing a concrete mix. First, the concrete must be workable and easy to cast in the forms in its fresh condition, even when the forms are packed with steel reinforcement. In this condition, it is the rheology of concrete that is important. Second, the mix must produce a hardened concrete of specified strength at 28 days (or similar specified time) that is durable and provides good serviceability.

In this laboratory exercise, a method of concrete mixture proportioning, named the trial batch method, will be explored. The concrete produced will be used in conducting typical tests to determine the principal characteristics of fresh concrete, including slump, flowability, air content, and density. The trial batch method is a simple, empirical approach to mixture design.

The objectives of this experiment are fourfold: (1) to use the trial batch mix method to determine optimum proportions of aggregates, cement, and water for concrete to meet specified slump requirements, (2) to learn concrete mixing practice in a laboratory environment, (3) to observe the characteristic properties of fresh concrete, and (4) to prepare 4"x8" concrete cylinders for subsequent evaluation.

Principles

In the trial batch method, an appropriate water-to-cement ratio (w/c , by mass) is first selected to obtain the desired strength (Table 1) and durability (Table 2); then a mixture is made with that specific w/c , incorporating fine and coarse aggregate to achieve the desired plastic consistency (i.e., slump and workability). In practice, this process is often iterative, where several batches are prepared and consequently modified to achieve the most economical mixture with the desired properties.

Compressive Strength at 28 days (psi)	Non-air-entrained concrete	Air-entrained concrete
7000	0.33	—
6000	0.41	0.32
5000	0.48	0.4
4000	0.57	0.48
3000	0.68	0.59
2000	0.82	0.74

Table 1. Minimum w/c to achieve design strength.

Exposure condition	Maximum w/c -ratio
Concrete with low permeability; exposed to water	0.5
Concrete exposed to freezing and thawing in a moist condition or deicers	0.45
For corrosion protection for reinforced concrete exposed to chlorides	0.4

Table 2. Maximum w/c for selected durability categories.

The trial method begins with the specification of the basic constituents: cement, water, coarse and fine aggregates, and target air content. The coarse and fine aggregates are assumed to be inert, thus the main variables in the mix are the cement, water, and air. The water to cement ratio (w/c) is the most important parameter, as the concrete strength (Table 1) is directly dependent on this quantity, which typically varies from about 0.35 for high-strength concrete, to about 0.6 for low-strength concrete (driveways and sidewalks). A lower w/c ratio decreases the permeability of the concrete, improving its durability by reducing the rates at which salt ions penetrate the concrete and lead to corrosion of the reinforcement (Table 2). Arbitrarily, the strength is customarily measured at 28 days after casting.

A slump, or measure of the flowability of the concrete, is also commonly specified to facilitate placing of the concrete in the formwork. The slump test consists of filling with fresh concrete and compacting an inverted steel cone in three layers. Once the cone is filled, the cone is lifted vertically and the amount that the concrete slumps is measured. For good workability, slumps in the range of 3 to 5 in. are commonly specified. The behavior of the concrete under this test is also a valuable indication of the cohesiveness of the mix. A well-proportioned mix will gradually slump to lower elevation and retain its original form, while a poor mix will crumble, segregate, and fall apart.

The air content also plays an important role in durability, especially if the concrete is intended for use in a region that undergoes cycles of freezing and thawing. When freezing occurs, the free water turns rapidly to ice, expanding by about 10%. Thus, there need to be many very

small, closely spaced air bubbles in the mix to allow this expansion without cracking the concrete. To increase freeze-thaw resistance, air-entrainment agents are added to concrete to raise the amount of air from 1-2% to about 5-7% of the total volume. The higher amount of air results in a lower strength, so for a given strength, a higher w/c is necessary if air entrainment is used (see Table 1). There are several techniques that can be used to measure the air content in fresh concrete, and the selection of which technique to use is based on equipment availability.

The strength gain of the concrete is also dependent on several other factors, with the curing temperature and humidity representing the other largest contributing factors to the strength. Curing at high temperature and humidity accelerate the strength gain significantly.

The following data is given for the materials in this laboratory:

- Cement: Normal cement (Type I) with a specific gravity (SG) of 3.15
- Slump: The desired initial slump is 3.5 + 0.5 in. This concrete is easily cast but will require vibration if there are small clearances between the steel reinforcement and the forms.
- Air content: The concrete mix will be specified as non-air-entrained. However, there will be some air entrapped. Assume 1.5% entrapped air.
- Water to cement ratio (w/c): This value will be variable, but the original mix will be for a w/c = 0.45.
- Coarse Aggregates: A #67 crushed granite gradation will be used. The coarse aggregate has a specific gravity (bulk SSD) of 2.65, an absorption capacity of 0.58%, a dry-rodded unit weight of 100 pcf, and a maximum aggregate size (MSA) of 3/4".
- Fine Aggregates: A natural sand will be used. The fine aggregate has a specific gravity (bulk SSD) of 2.63 and an absorption capacity of 0.40%.
- Actual moisture contents (MC) for both coarse and fine aggregate are to be determined: The mix design will be for the saturated surface dry (SSD) condition.

The quantities of the materials used for this experiment are listed in Table 3 below. The quantity of material should be enough to produce concrete to cast ten 4 in. diameter by 8 in. long cylinder specimens. The amount of coarse aggregate and sand will be adjusted during batching to achieve adequate workability and slump for the concrete mix.

Party No.	Test Age	Curing	w/c	Initial Wt. Per Batch (lb.)			
				Cement	Water	C. Agg.	Sand
C1-G1	28 days	Air	0.45	13.4	6.0	40	30

Table 3. Initial quantity of materials for concrete batching laboratory (lb.).

The mix design described herein does not initially contain any admixtures. Admixtures are chemical additives that are used either to improve the workability and economy of the fresh concrete or to increase the concrete's long-term durability. Examples of admixtures used to improve workability include superplasticizers, or chemicals that considerably reduce the viscosity of a mix for a short period of time in order to allow for ease of placement into the forms. Other examples of admixtures used for economic reasons include high range water reducers, or additives that maintain the same workability with less water and consequently less cement (for a constant w/c ratio). Finally, examples of admixtures used to improve the durability include air-entrainment agents, or chemicals that create many small, well-dispersed air bubbles that allow free water in the hardened concrete to expand upon freezing without cracking.

Procedure

The procedure below first describes the mixing process and then the typical tests (slump, density, and air content) used in the field to determine workability, consistency and quality. The procedure described here has been found to work well with a small concrete mixer.

1. Mixing Concrete by the Trial Method

1. Weigh quantities of coarse aggregate and fine aggregate and store them in separate containers. Record the exact weights on the data sheet.
2. Weigh the quantity of cement given above in Table 1, and place it in a separate container.
3. Weigh the quantity of mixing water given above in Table 1, and place it in a container.
4. Dampen the inside of the mixer and all tools that will be used, so that they are wet but not with any standing water.
5. Put the coarse aggregate, fine aggregate, and about 1/5 of the water into the small concrete mixer and mix for about 2 minutes.
6. With the mixer still rotating, begin to add the cement and additional water in small increments (10% to 20% of the total in each step) and mix for an additional 5 minutes.
7. Stop the mixer and test the slump of the concrete mix. In testing the slump, dampen the slump cone and place in the mixing pan. Hold the slump cone down *firmly* against the pan. Fill the slump cone with concrete in three layers, each approximately one-third of the volume of the slump cone for each layer.
8. Rod each layer with 25 strokes, distributed uniformly over the cross-section of the cone. The rod should slightly penetrate into the previous layer. After the top layer has been rodded, strike off excess concrete with the tamping rod, so that the cone is filled exactly.
9. Immediately remove the cone from the concrete by raising it carefully in a vertical direction. Measure the "slump" of the concrete by determining the difference between the height of the mold and the height of the subsided concrete.
10. After the slump measurement is completed, tap the side of the concrete frustum gently with the tamping rod.
11. At this point the slump of the mixture should be in the 3 to 4 in. range. If the slump is too low, or the mix appears to be harsh, gradually add small quantities of fine or coarse aggregate (or both), thoroughly remix the concrete, and retest the slump. Repeat this process until the mix reaches the desired slump and consistency. Be sure that to keep track of the additional amounts of material used.

12. When the batch is judged to be satisfactory by the slump test, weigh the remaining aggregates and record in the data sheet. Compute the actual amount of coarse and fine aggregates used in the concrete mix from the initial weights.
13. Determine the concrete mix's unit weight by filling and weighing a 1 cubic foot container. The container should be filled and rodded in the same manner as the cone for the slump test.

2. Air-Entrainment Testing

If the concrete mix was designed for a region with freeze-thaw cycles, it is probable that an air-entrainment admixture content would have been specified to bring the total air content to a range of 6% to 8%. To demonstrate this effect, take the remaining concrete and remix it while adding the air-entrainment admixture. First, mix for about 3 minutes, and then conduct an air content test by using an air entrainment apparatus. Keep in mind that the procedure for conducting the test is device specific, so the following procedure refers exclusively to the device used in this video, or similar.

1. Fill the bottom container with concrete following the instructions for obtaining a unit weight.
2. Close the red-colored main air valve on the top of the air receiver.
3. Open both petcocks located on the top of the lid.
4. Place lid on the material container and close the four toggle clamps.
5. Pour water into the funnel until water comes out the petcock in the center of the lid.
6. Jar the meter gently until no air bubbles come out through the center petcock. Close both petcocks.
7. Close the main air valve and bleeder valve in the end of the air receiver.
8. Gently pump air into the receiver until gauge hand gets close to the red line. Make sure the hand passes the initial starting point. It does not matter whether the hand is on one side or the other side of the red line.
9. Tap the gauge gently with one hand. At the same time, crack the bleeder valve until the gauge hand rests exactly on the initial starting point.
10. Quickly close the bleeder valve. Open the main air valve between the air receiver and the material container.
11. Jar the container slightly after releasing the pressure to allow particles to rearrange. Tap the gauge gently until the gauge hand comes to rest. Record the reading as the percent of air entrained.

3. Concrete Test Cylinder Preparation

1. Fill the cylinder molds by placing the concrete into the cylinder mold in three layers of approximately equal volume.
2. Rod each layer with 25 strokes using a small tamping rod (1/4 in. diameter rod). Distribute the strokes uniformly over the cross-section of the mold.
3. After the top layer has been rodded, strike off the surface of the concrete with a trowel. Fill a total of ten concrete cylinder specimens. Measure the weight of all ten cylinder molds filled with concrete and record the weight on the data sheet.
4. Cover the concrete cylinders with a plastic bag to prevent evaporation of water from the concrete.
5. For the final mix, calculate the required weight of materials to make one cubic yard of concrete. Record these results in the data sheet.
6. After 24 + 8 hours, strip the disposable plastic molds from the concrete cylinder specimens. The cylinders are then placed in the curing environment listed in Table 1. Typical curing regimens are: (1) fog room curing at 73.5+3.5°F (23+2°C) and 100% RH, per ASTM C 192, (2) ambient curing in the lab, and (3) insulated box curing (i.e., cure box). We will use ambient curing in this experiment.

4. Adding Superplasticizers

1. To demonstrate the use of an admixture, return all concrete to the mixer and add a small amount of superplasticizer. Mix well for 3 minutes and conduct a flow table test.
2. Wet the table and the mold. Wipe off excess water.
3. While holding the mold firmly, fill the mold with concrete in two layers. Rod each layer 25 times, making sure that rodding is uniform across the cross-sectional area.
4. Strike off the top of the mold, so that the mold is filled exactly.
5. Remove the mold with a steady upward pull.
6. Using the handle, raise and drop the table from a height of 0.5 in, 15 times in about 15 seconds.
7. Take the average of six symmetrically distributed caliper measurements to the nearest 1/4 in. This value will be the diameter of the spread concrete.

Results

In general, mixes such as the one described above will have slumps of 3 to 4 inches. Such values are common for small jobs with little steel congestion in the forms. In modern construction, the widespread use of superplasticizers has meant that it is economical to get much higher slumps (6 to 10 inches, i.e., self-leveling concrete). Non-air-entrained mixes will show air contents below 2%, while air-entrained mixes, depending on admixture dosage, will show 5% to 8% air content. The unit weight of normal-weight concretes is around 145 to 150 pounds per cubic foot, but concrete made with lightweight aggregates (i.e., expanded shales) may be as light as 100 to 120 pounds per cubic foot.

Applications and Summary

Slump cone and flow table tests are in-situ test results used to determine if the concrete being delivered to the site has the specified workability. These tests are meant to ensure an adequate rheology for the mix, i.e., a good initial "viscosity" that lasts long enough for the concrete to get from the batching plant to its final position in the forms without leaving large voids or similar defects around the reinforcement. Additionally, the

air-content test is key to ensuring long-term durability in areas where freeze-thaw cycles occur. It should be noted that all of these tests are at best an attempt to determine quantities that are difficult to measure under the best of circumstances. Under the time pressure and chaos of a work site, these tests provide indirect measures of important short- and long-term properties.

The test described herein is used every day in thousands of construction sites in the United States and across the world. The main application for a test of this type is to provide quality control and quality assurance. Some of the test cylinders cast in this laboratory will be cured under specified conditions (fog room curing at $73.5 \pm 3.5^\circ\text{F}$ and 100% relative humidity) and tested at 28 days to determine if the mix design was appropriate. The relatively high temperature and humidity ensures that most of the cement will hydrate, thus the w/c ratio for this mix will provide strong and durable concrete. This experimental work ensures that batching plants meet the required specifications. Some of the test cylinders will be cured at ambient conditions at the work site to determine how fast the in-situ concrete is curing. On site, the development of strength is tied mostly to temperature and humidity conditions, which are random and can vary substantially over a 28-day period. To offset these conditions, the concept of concrete maturity is used often. The maturity of the concrete is calculated in degree days, generally summing the number of days times the difference between the average daily temperature and a reference temperature (generally 32°F). When the number of degree-days reaches one thousand, the concrete is assumed to have reached its intended strength.