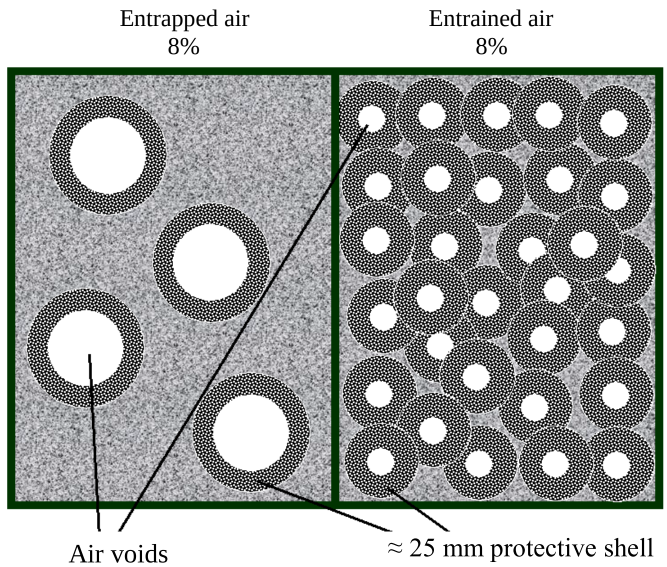
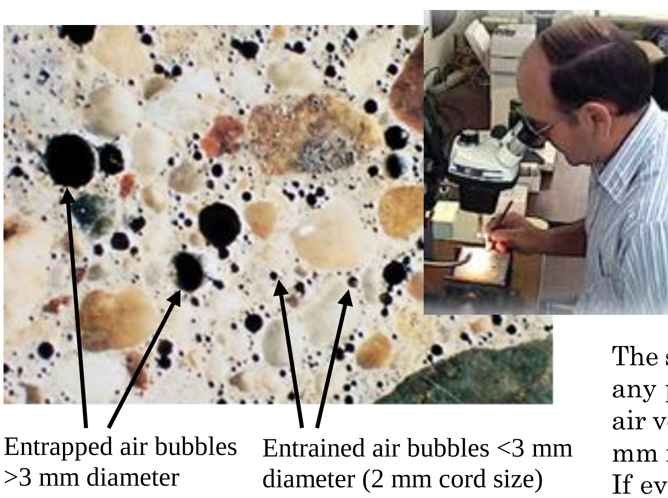
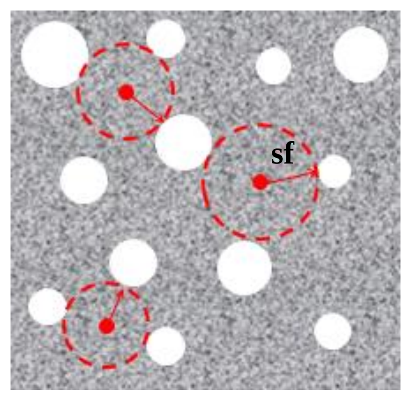
**Freeze-Thaw damage, background**

The durability of concrete subjected to wetting and cycles of freezing and thawing can be enhanced by deliberately introducing many, small and closely spaced air bubbles (air voids) in the cement paste. During freezing, the ice formed (about 9% larger volume) in the capillary pores of the paste will expand into adjacent air voids without cracking the paste, provided the air-void spacing and the size distribution of the air voids are within certain limits.




On the left two cases are shown with the same amount of total air, one with few large air-bubbles and one with many small ones in the paste.
In the "shell" around the bubbles, approximately 0.25 mm thick, the ice formed during freezing in the capillary pores in proximity to an air entrained void will expand into the air bubble and not cause cracking of the paste. Upon thawing, the ice will melt in the bubble and be transferred back into the capillary pores.
Consequently, a good frost resistant paste will have to contain many small bubbles closely spaced.




The spacing factor "sf" is the maximum distance from any point in the cement paste to the periphery of an air void. Generally, the spacing factor has to be <0.20 mm for adequate resistance to freezing and thawing. If evaluated by the specific surface (bubble surface / bubble volume), the value has to be >25 $mm^{-1}$

*Example of outdoor exposure to Freezing and Thawing after 40 years.*

*Left: Concrete with improper air-void system.*
*Right: concrete with correct air entrainment.*

*Source: PCA*

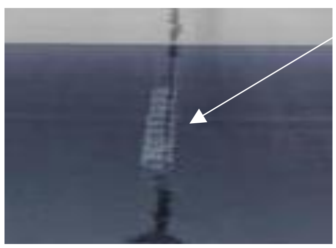

*Example of Freeze and Thaw cracking of the longitudinal joints of a concrete highway due to an improper air-void system in the presence of wet (saturated) concrete and freeze-thaw cycles.*

*Source: KDOT*

*Centerline joint spalling of a highway after 10 years in service in a freeze-thaw environment due to improper air-void structure in the paste and presence of moist/water in the joints*

*Note the centerline joint under the bridge is not spalled. Under winter freezing and thawing conditions, the sun does not reach this area to thaw the concrete, hence reduced numbers of freeze-thaw cycles occurred.*

*Source: KDOT*



**Test Methods**

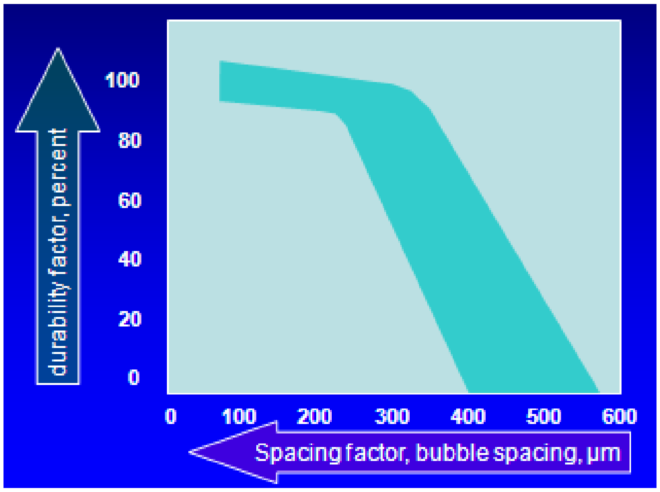
**ASTM C457-16.** Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete

The spacing factor and the specific surface of the air-void system are determined typically according to this ASTM standard or according to EN 480-11 "Admixtures for concrete, mortar and grout - Test methods - Part 11: Determination of air void characteristics in hardened concrete."
These methods require obtaining a core from the hardened concrete on-site and preparing a properly polished specimen in the laboratory as illustrated in the photo previous page. This preparation requires specialized equipment, a well-trained technician and it takes time.
The spacing factor and the specific surface are then determined manually by the linear traverse method using a microscope, or by an automated image analyses system like the **RapidAir**. Determination of the air-void structure in this manner cannot produce timely information during construction, which would be needed to make adjustments e.g. to the concrete mixture if the spacing factor and the specific surface are not within specified limits.
In other words, microscope examination of hardened concrete gives good information, however it is slow, expensive and it gives no timely information.

**ASTM C666-15.** Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing.

This standard covers the determination of the resistance of concrete specimens to rapidly repeated cycles of freezing and thawing in the laboratory. Each specimen is subjected to maximum 300

freeze/thaw cycles and tested for the relative dynamic modulus of elasticity regularly during cycling. A Durability Factor is then calculated depending on how important the change in the elastic properties is.
The typical relationship between the spacing factor and the durability factor is shown in the figure on the right. It can be seen that durability increases as bubble spacing decreasing, illustrating that a good durability is present if the spacing factor is less than about 0.20 mm.



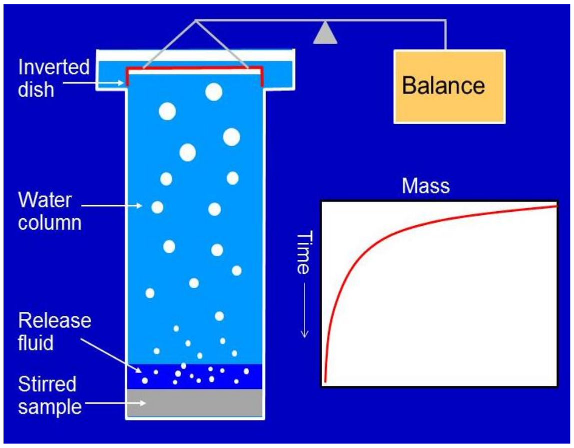

**The AVA-3000**

The AVA (Air Void Analyzer) is used to measure the size distribution of voids and the air-void parameters (spacing factor and specific surface) of the fresh, still-plastic, air-entrained concrete.


**AVA-3000** *System consisting of laptop with installed software, base unit, riser column, water tank and sampling equipment.*

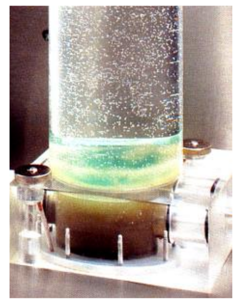
**Principle**

A mortar sample of the air entrained concrete is obtained from the fresh concrete with a sampling tool and injected into the blue AVA release liquid at the bottom of a riser column with water above. The mortar sample is stirred gently into the release liquid by which the air bubbles are released and start rising through the water following the Stoke´s Law: larger bubbles will rise faster than smaller bubbles.
Due to the blue release liquid that has the proper viscosity and hydrophilic character, the air bubbles will retain their original sizes and neither coalesce nor disintegrate into smaller bubbles during



sampling, injection and mixing. The temperature of the liquid and of the water has to be within 21°C and 25°C.
The air bubbles rising through the water column are collected under an inverted and submerged petri dish (buoyancy pan) attached to a sensitive balance. As air bubbles accumulate under the dish, the weight of the dish decreases. The weight of the dish is recorded as a function of time.
Based on the recorded change in apparent mass of the pan, an algorithm calculates the size distribution of the collected air bubbles. From the size distribution, the spacing factor and the specific surface are calculated. The algorithm ensures the parameters are similar to obtained from ASTM C457 linear traverse measurements.

**Test description**

- A sample of the mortar of the air-entrained concrete is taken by vibrating a wire cage into the fresh concrete which excludes particles larger than 6 mm. A syringe is used to collect a 20 $cm^3$ mortar specimen from within the cage.
- The mix proportions for the concrete is entered into the software.
- The riser column has the blue AVA release liquid at the bottom and water above it. The specimen is injected into the riser column and the program started. Mortar and liquid are stirred gently by a magnetic stirrer for 30 seconds by which the air voids are released.
- The bubbles rise through the liquids at rates that depend on their size, which results in a separation in time when different size bubbles arrive at the top of the column and are collected under a submerged and inverted glass dish attached to a high precision balance. The software records the change in mass of the inverted dish as a function of time.
- For each succeeding period, the size of the bubbles collected under the dish decreases. The measurement continues for 25 minutes unless no mass change is recorded for 2 consecutive minutes, in which case the measurement is stopped.
- The AVA software processes the time history of the balance readings and calculates the size distribution of the air bubbles, reported in a graph and a histogram, and the air-void parameters, spacing factor and specific surface.

**System Features**

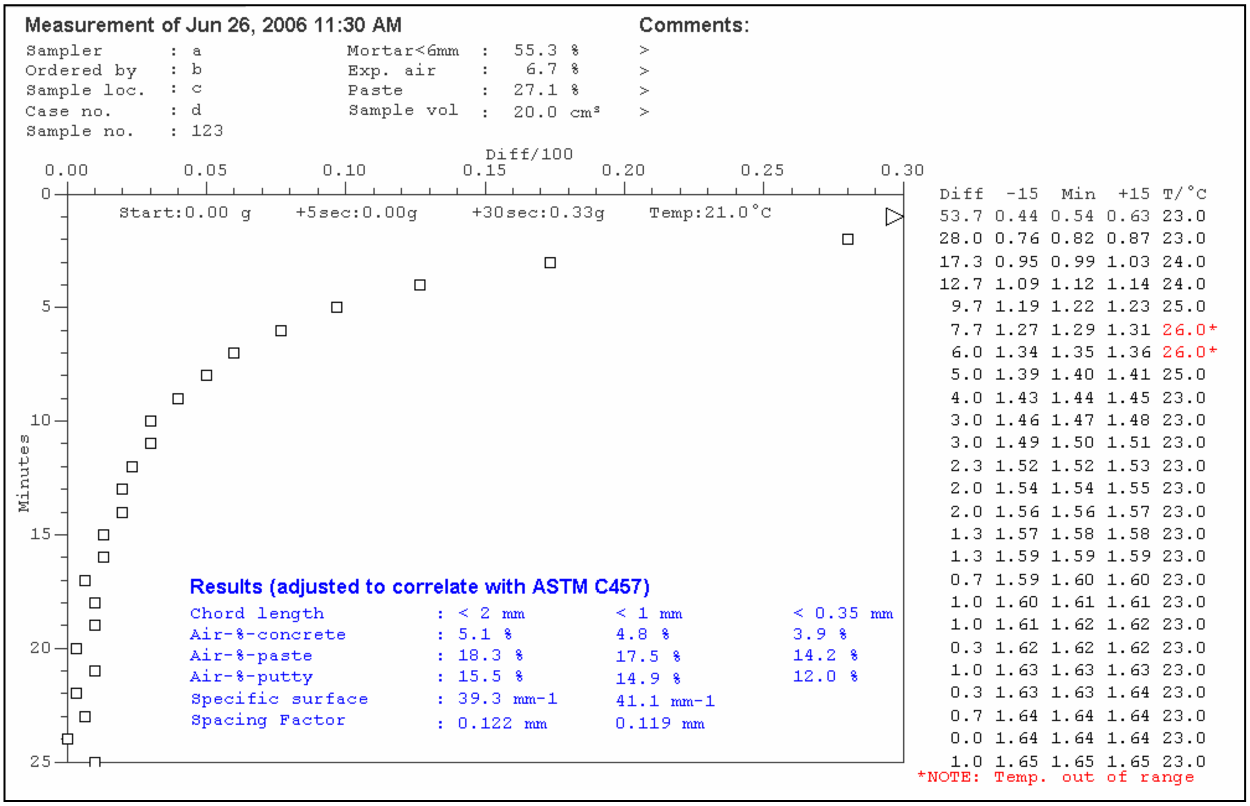
- Accurate measurement of the essential air void parameters, the spacing factor and the specific surface of the air bubbles of air-entrained, still plastic concrete.
- Documenting not only the air void parameters, but also the size distribution in bubble classes and accumulated bubble distribution for bubbles < 2 mm cord size (3 mm diameter).
- Visualization of the air bubbles rising through the riser columns water.
- Scientifically based, documented and investigated in many test programs worldwide.
- Useful to establish a relationship to durability determined by freeze-thaw tests, ASTM C666-15.

- Close relationships to spacing factor and specific surface as determined by ASTM C457-16.
- Easy sampling within 5 minutes and a maximum testing time of 25 minutes.
- Applicable anywhere in the production process, e.g. in the laboratory, at the ready mix plant, on site after transportation, after pumping, manipulation or consolidation of the concrete.
- Real time data acquisition (buoyancy versus time) shown on the laptop.
- Windshield to cover the balance for use on-site.
- 35 liter tank for de-aerating the water used in the riser column and for temperature regulation of the water and the release liquid for releasing the air bubbles in the 20 $cm^3$ sample.
- AVA-3000 is the latest development in the AVA series
- 15 years of experience among major cement and concrete producers, admixture companies and state / government institutions worldwide.

**Documentation**

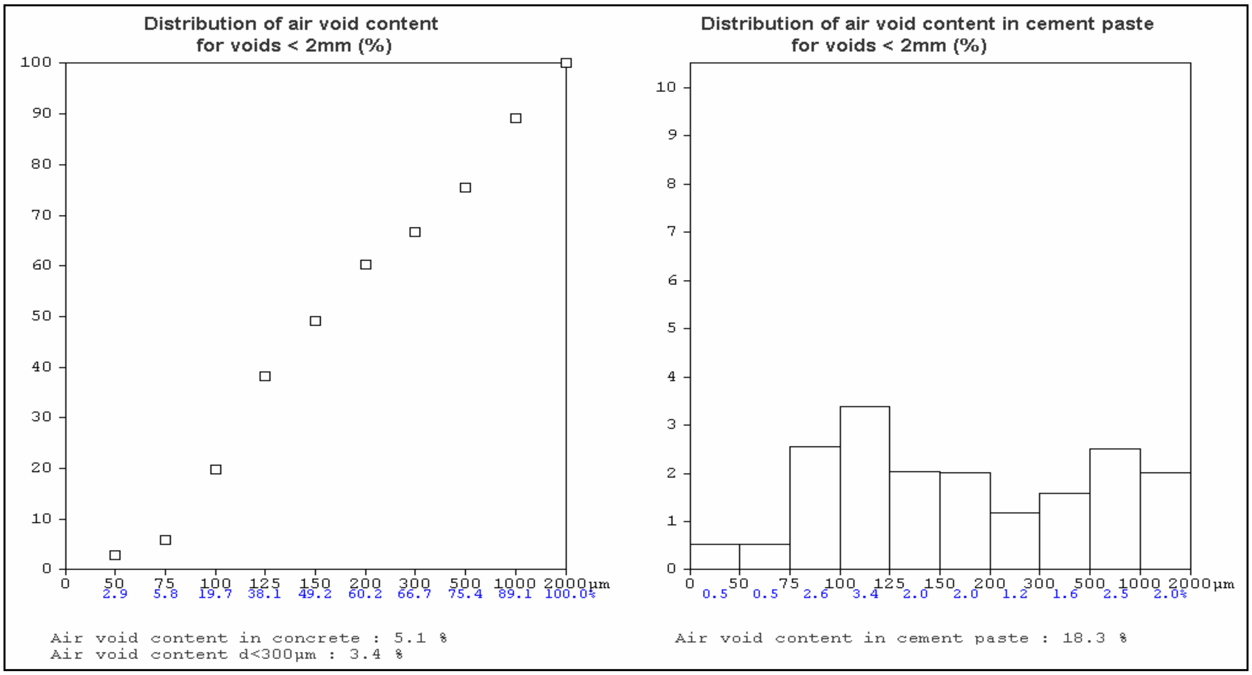
After the test has been completed, the following documentation is available on the laptop screen, ready for printout:

- The change in mass of the buoyancy dish (x-axis) as a function of time (y-axis);
- The results of the analyses, including: air content of the sample, **spacing factor** and **specific surface** for cord length of air bubbles <2 mm and <1 mm.
- The input mix parameters (mortar %, exp. air %, paste % and sample volume)
- Comments

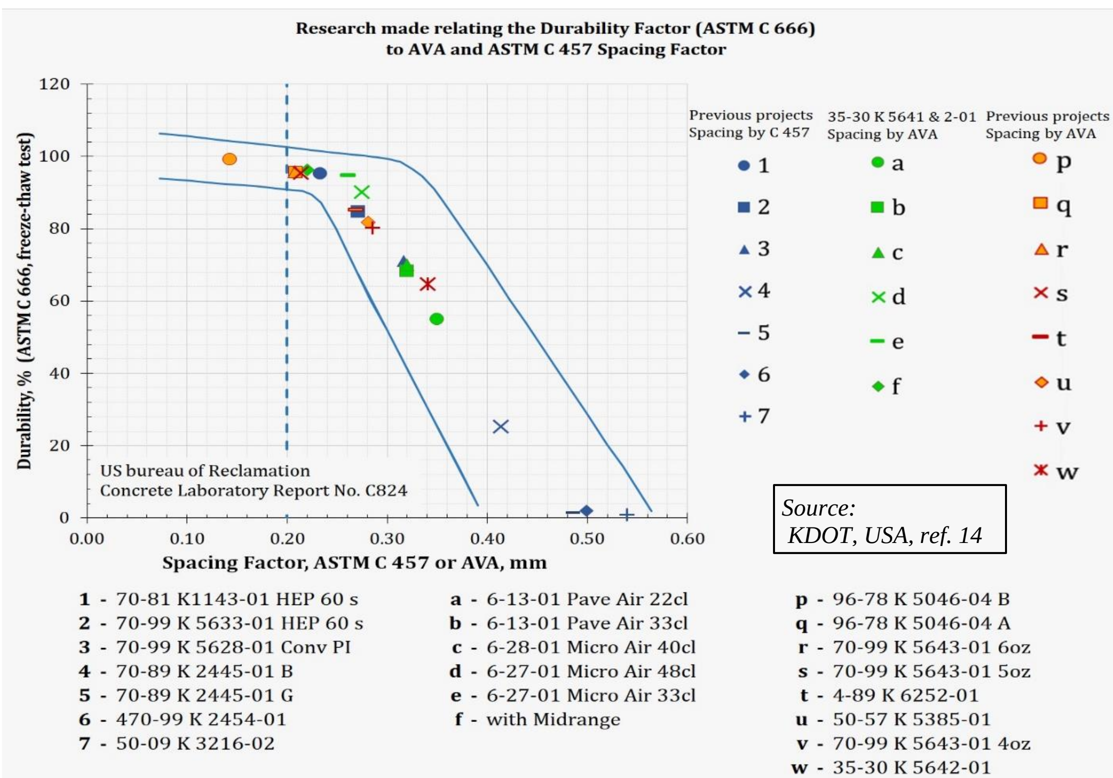



In addition, the following information about the air voids is available:

- The size distribution of air voids less than 2 mm cord size – 3 mm diameter voids (left), and
- A histogram of air-void sizes less than 2 mm cord sizes (right).



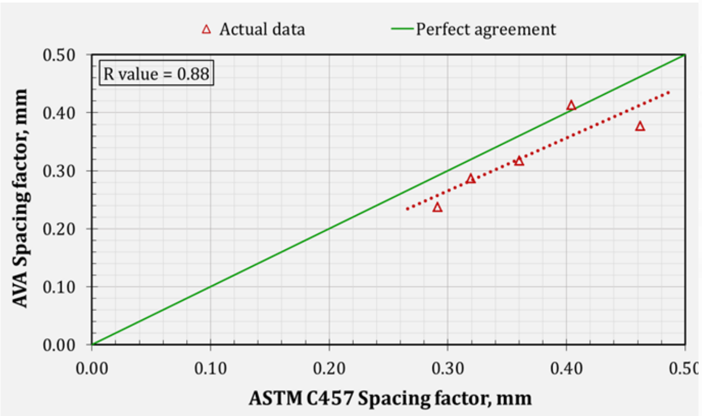

## Comparisons to Durability Factor



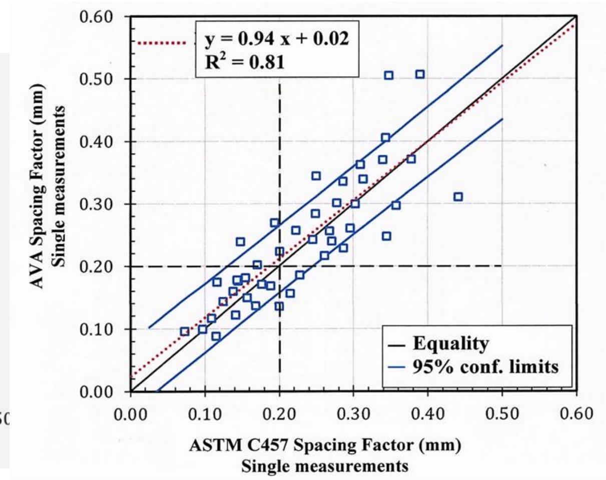

It can be seen that the spacing factor obtained by the two methods, ASTM C 457 and the AVA, are evaluating the durability of the concrete specimens by ASTM C666 almost identically.

**Comparisons between spacing factor evaluated by AVA and ASTM C457:**

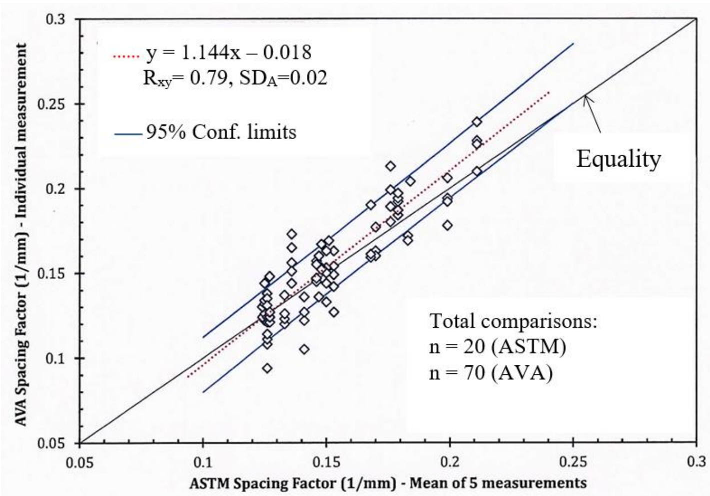
The figures below compare air-void parameters obtained on fresh concrete samples using the **AVA** with the corresponding parameters obtained by microscopical analysis of the hardened concrete and show the good correlation that AVA gives.

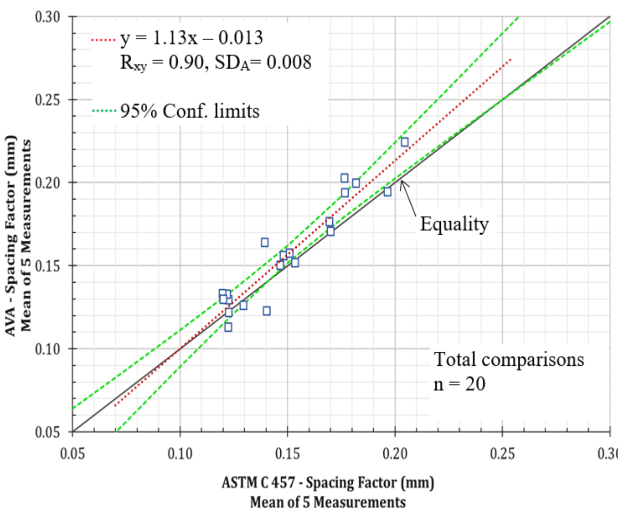



*Single measurements of AVA spacing factor related to single ASTM C457 measurements, KDOT, USA ref. 11 & 14*




*Single measurements of AVA spacing factor related to single ASTM C457 measurements, FHWA, USA, ref. 4*




*AVA spacing factor related to ASTM C457 spacing factor, single AVA measurements to mean of five ASTM measurements (left) and mean of five AVA measurements to mean of five ASTM measurements, DBT, Denmark, ref. 1*

## AVA-3000 Specifications

- USB interface
- Measuring time = 25 min./test
- Sample size for a test = 20 mL
- Real time data acquisition (weight vs time) showed on screen.
- Reports voids' curve of size distribution and histogram for void size < 2 mm.
- Algorithm calculates spacing factor and surface area in relation to ASTM C457.

- Operational voltage 240 V AC.
- Weight: 13.8 kg (bath tank) and 7.8 kg (base unit)
- Dimensions: 40 x 40 x 30 cm (bath tank) and 47 x 48 x 21 cm (base unit)
- Mini balance: 300 g capacity, 0.01 g resolution (0.001 g internal accuracy)
- Magnetic stirrer: 150 mNm, 4000 rpm
- 35 L bath tank with de-aerating pump and heater

## AVA-3000 Components

The AVA-3000 is delivered in two cases:


*Aluminum case with base unit and accessories*

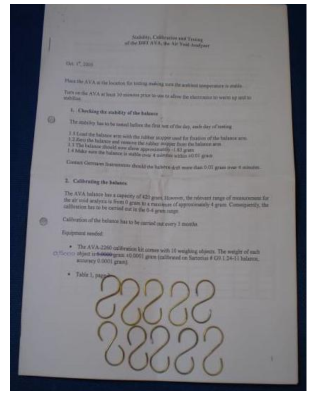
| Description | Order # |
|---|---|
| Alumina case with pouch and foam insert | AVA-3005 |
| Base Unit | AVA-3010 |
| Riser Column | AVA-3020 |
| Windshield | AVA-3022 |
| 6 mm Screws, 2 pcs | AVA-3025 |
| Stirrer Pin, with one spare | AVA-3028 |
| Piston | AVA-3030 |
| Buoyancy Pan | AVA-3040 |
| Wire Cage | AVA-3050 |
| Vibrator | AVA-3060 |
| Funnel | AVA-3080 |
| Graduated Sampling Syringes, 3 pcs | AVA-3090 |
| Brush | AVA-3130 |
| Template with center hole | AVA-3140 |
| USB Cord | AVA-3160 |
| Power Cable, 110VAC or 220VAC | AVA-3170 |
| Rubber Suction Ball | AVA-3180 |
| Vaseline, can | AVA-3190 |
| Vaseline, Tube | AVA-3200 |
| CD with AVA Literature | AVA-3210 |
| AVA-3000 software CD | AVA-3220 |
| AVA-3000 Manual | AVA-3230 |
| Flashlight | AVA-3250 |

*Aluminum case with water tank for de-aerating and tempering, laptop and drill machine*

| Description | Order # |
|---|---|
| Alumina case with foam insert | AVA-3300 |
| Water tank with temperature regulator and stirring | AVA-3310 |
| Power cable, 110 V or 210 V | AVA-3315 |
| Top Lids, 2 pcs | AVA-3320 |
| 2L Containers for release liquid, 2 pcs | AVA-3330 |
| Laptop with installed software | AVA-3340 |
| Electric Drill, 110 V or 210 V | AVA-3350 |

To be ordered separately:

| Description | Order # |
|---|---|
| AVA Release liquid | AVA-3240 |
| Verification kit | AVA-3260 |



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## Standards related to AVA:


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