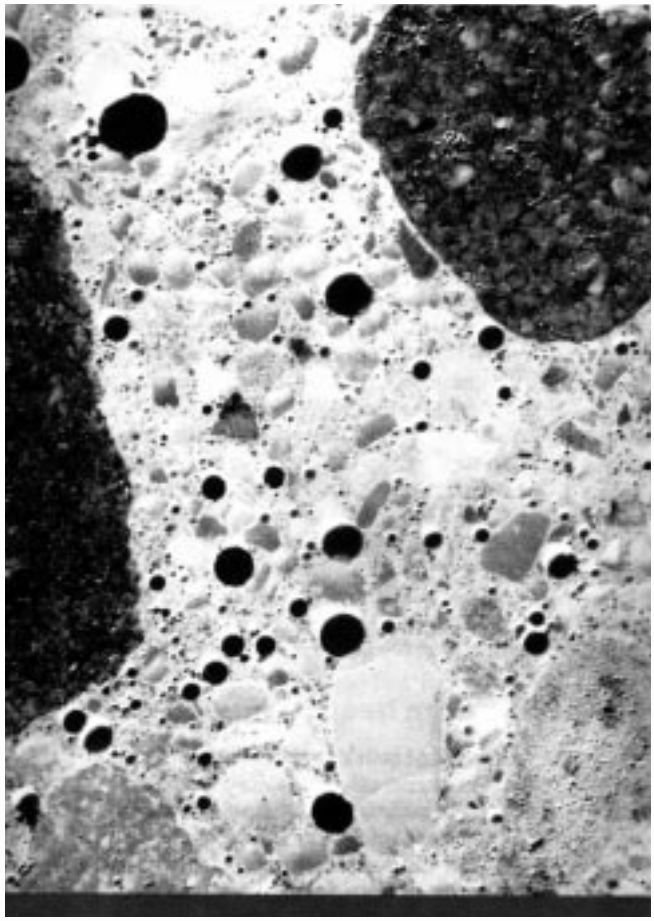
The Air-Void System in Concrete

Some uncertainty has been expressed regarding the meaning of terms used by concrete technologists to characterize the air-void system in concrete. The following descriptions are provided to help clarify this situation.

The term "air-void system" normally refers to the collective presence of discrete air bubbles distributed throughout the cement paste matrix of concrete. These bubbles are of such size that only the larger ones may be seen with the unaided eye. However, these and smaller bubbles are readily seen under 10 to 25, or greater, magnification. The bubbles are generated during mixing of fresh concrete, and, in concrete with intentionally entrained air, are stabilized by the use of air-entraining admixtures incorporated into the concrete mix.

Non-air-entrained concrete also possesses an air-void system. In this case, voids or bubbles have become entrapped in the concrete primarily because of inadequate consolidation. Voids of this type are present in virtually all concrete, including air-entrained concrete. They are often distinguished as such by their non-spherical or distorted shape, and their considerably greater size.

Several parameters are used to characterize the nature of the air-void system in air-entrained and non-air-entrained concrete. These parameters are measures of the volume of air present, the average size of voids, and the average distance between voids. To obtain values for these parameters, measurements are made in the laboratory on polished surfaces of concrete according to ASTM C 457, Standard Practice for Microscopical Determination of Air-Void Content and Parameters of the Air-Void System in Hardened Concrete. The parameters normally used to characterize the air-void system of hardened concrete are as follows:



Polished section of air-entrained concrete as seen through a microscope.

Air content (A) denotes the total volume of optically visible air voids in the cement paste matrix of the concrete. It is normally expressed as percent by volume of the concrete (aggregate + paste + air). Sometimes data for both entrained and entrapped air voids are reported. Distinction between the two is arbitrary, and is based on shape and size of voids. Entrapped air voids generally are not spherical in shape, in contrast to entrained air voids, and are usually categorized as being larger than approximately 0.04 in. (1 mm). Both classes of air voids have an impact on the frost resistance of concrete, but the smaller more frequently occurring and more uniformly distributed entrained-air voids are the ones relied upon to provide permanent frost protection, thus the distinction between the two types. The total amount (volume) of air required is a function of maximum aggregate size. The air content of concrete with 3/4-in. (19-mm) maximum-size aggregate would be about 6%.

Voids per inch (n) refers to the average number of air voids intersected per inch of traverse of the polished concrete surface (aggregate + paste + air). This parameter is utilized in calculating the "fineness" of the air-void system, and is used in conjunction with the percent air to estimate whether the concrete is adequately air-entrained. Using these two parameters, a rule-of-thumb states that the number of voids per inch of traverse should be at least twice the percent air to indicate a reasonably well air-entrained concrete.

Specific surface (α) refers to the calculated average surface area of air voids measured per unit volume of air. It is usually expressed as sq in. per cu in. Thus, the "finer" the air-void system, the greater the specific surface area. For adequate air entrainment in ordinary concrete, specific surface areas are expected to exceed 600 sq in. per cu in. (25 mm^2/mm^3).

Void spacing factor ($\bar{L}$) is an approximation of the average distance between individual air bubbles in the cement paste matrix of concrete. It very closely correlates with frost resistance of concrete containing durable aggregate. It should be no greater than 0.008 in. (0.20 mm), but may be less. The most precise calculation of void spacing factor requires determination of the cement paste content of the concrete, but reasonably good estimates can be made from graphs provided in ASTM C 457.

Summary

Overall, linear traverse procedures can provide the information necessary to calculate the above four parameters for characterizing the air-void system in concrete. Of the four, air content and void-spacing factor are the most critical ones on which to base an assessment of the adequacy of an air-void system for frost protection. For strength related considerations, only air content determination, of the four, is necessary.

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