

# ANALISIS DEL CONTENIDO DE AIRE EN EL CONCRETO FRESCO

Carolyn M. Hansson y Anders Henrichsen

**Sinopsis:** Las técnicas normalizadas para determinar los parámetros de contenido de aire en concretos con aire incluido son costosas, consumen tiempo y son subjetivas. Además, estas son técnicas para el *control de la calidad* ya que las medidas se hacen en el concreto endurecido, el cual no puede, obviamente, ser modificado. Este trabajo describe una nueva técnica para asegurar la *calidad*, que se ha desarrollado para permitir determinar los mismos parámetros en el concreto fresco mientras aún está plástico. La técnica involucra la dispersión de los huecos de una muestra de mortero del concreto en un líquido viscoso. Las burbujas en el líquido ascienden con velocidades que son proporcionales a su tamaño y, mediante el monitoreo del volumen de aire que asciende en función del tiempo, los parámetros de los huecos de aire (volumen de aire, superficie específica y factor de espaciamiento) pueden ser determinados aproximadamente en 30 minutos. Además, la técnica es automática y aporta una determinación más objetiva de los parámetros de huecos de aire que los ensayos regulares.

**Palabras clave:** concreto con aire incluido, distribución de huecos de aire, superficie específica, factor de espaciamiento, resistencia al congelamiento/descongelamiento.

# AIR VOID ANALYSIS OF FRESH CONCRETE

Carolyn M. Hansson and Anders Henrichsen

**Synopsis:** The standard techniques for determining the air void parameters in air entrained concrete are costly, time consuming and subjective. Furthermore, there are *quality control* techniques since the measurements are made on the hardened concrete which cannot, obviously, be modified. This paper describes a new, *quality assurance*, technique which has been developed to allow the same parameters to be determined in the fresh concrete while it still plastic, thereby allowing mixes to be modified, if necessary. The technique involves dispersating the void from a mortar sample of the concrete into a viscous liquid. The bubbles in the liquid rise at rates proportional to their size and, by monitoring the volume of air rising as a function of time, the air void parameters (air volume, specific surface and spacing factor) can be determined within approx. 30 min. Moreover, the technique is automatic and provides a more objective determination of air void parameters than do the same standard tests.

**Keywords:** Air entrained concrete, air void distribution, specific surface, spacing factor, freeze/thaw resistance.



**Carolyn M. Hansson** is Professor and Head of Materials and Metallurgical Engineering at Queen's University, Kingston, Canada since 1990. Prior to this, she spent nine years in industrial research and consulting in Denmark. She also worked in industrial research (at Martin Marietta Laboratories and At&T Bell Laboratories) and academic (at Columbia University and the State University of New York at Stony Brook) in USA. She graduated from Imperial College, London University and has spent most of her career since then investigating degradation mechanisms of different materials and techniques for improving their durability.

**Anders Henriksen** Dansk Beton Teknik A/S, Hellerup Denmark.

## INTRODUCTION

When concrete is exposed to repeated freezing and thawing, the resultant expansion and contraction of the pore solution can produce internal stresses which are sufficient to crack and spall the concrete. It has been shown [1] that a system of fine air voids well dispersed throughout the cement paste can provide space for the water to expand into as it freezes and, thereby, reduce or eliminate the internal stresses. The air void system is usually provided by the addition to the concrete mix of an air entraining agent. These are normally organic compounds, such as vinsol resin, with long straight molecular chains with a hydrophobic group at one end and a hydrophilic group at the other. The effect of the hydrophilic group is that the compound is soluble in aqueous solutions while the hydrophobic group reduces the solution's surface tension. This makes it easier for air to be mixed into the concrete and for bubbles to form without coalescing.

Experiments have demonstrated that, for good freeze/thaw resistance, the voids should be in the range of 5 - 200  $\mu\text{m}$ ; voids larger than this do not contribute to the frost resistance [2]; the specific surface (ie. the surface area to volume ratio) should be  $\geq 20 \text{ mm}^2$  and the average spacing between the voids should  $\leq 200 \mu\text{m}$ . These values are now generally included in specifications for frost resistant concrete. Questions have recently been raised about the necessity of these stringent requirements in, for example, concretes containing pozzolans and having very low water/cement ratios, but that is not the subject of this paper.

Having specified an air void system, it is, of course, then necessary to be able to determine whether or not the concrete meets the specifications and a method of so doing is described in the ASTM 457: [3]. In this method, the void system is quantitatively analyzed on a polished surface of the hardened concrete. While, theoretically, this is an acceptable technique, it does have some serious disadvantages which may be enumerated as follows.

1. The concrete must be hardened by which time it is too late to rectify any problems.

2. Sample preparation requires coring, sectioning, grinding and polishing. This is time consuming and costly and it is difficult to produce a representative section because, for example, pull out of particles from the surface results in holes which can be interpreted as air voids.

3. The optical micrographic analysis is both tedious and time consuming. More importantly, the reliability of the results is dependent on the ability of the operator to distinguish firstly between voids in the aggregate and voids in the paste and, secondly, between glassy spheres in fly ash and voids in the paste.

The fresh concrete air void analysis technique was developed [4] to give the same information as is provided by the ASTM 457 Standard Practice while avoiding the disadvantages of that procedure described above.

## PRINCIPLES OF THE TEST METHOD

The air voids developed in the fresh concrete by the addition of an air entraining agent (together with the entrapped air) are released into a viscous liquid, the properties of which allow the resulting bubbles to retain their original size and neither coalesce nor disintegrate into a number of smaller bubbles. The bubbles then rise through the liquid at rates dependent on their size (according to Stokes Law) and enter a column of water above the liquid. The viscosity of the liquid slows the initial rise of the bubbles and provides a measurable separation in time between the appearance at the top of the column, of bubbles of different sizes rising from the same layer of the liquid. The bubbles rise through the column of water and collect under a submerged buoyancy recorder which is attached to a balance. The change in buoyancy with time is monitored by computer. The bubble size distribution, such as that illustrated in Fig. 1, in each 15 s interval has been measured empirically and, on the basis of this empirical calibration, the recorded change in buoyancy with time can be related to the number of bubbles of different size. From this data, the following air void parameters specified by ASTM Standard Practice 457 are calculated:

- air volume in voids of diameter  $< 3.0 \text{ mm}$ ,  $< 1.0 \text{ mm}$  and  $< 0.5 \text{ mm}$  (as volume % of concrete and as volume % of paste)
- spacing factor (in mm)
- specific surface (in  $\text{mm}^2$ )

These parameters have been calculated to correspond to those that would be obtained from linear traverse measurements on a plane surface of the hardened concrete making the assumptions used in the ASTM 457 practice, namely (i) that the average measured chord length is equal to 2/3 of the true void diameter and (ii) for calculations of specific surface and spacing factor, that the voids are all of the same size and that they are located at the lattice points of a regular cubic array.



In addition, the data can be presented as (i) a graph of cumulative fraction of voids (as % of concrete) versus the true void diameter; (ii) a bar chart of the actual void volume (as % of the paste) in different ranges of void diameter.

### TEST PROCEDURE

Samples can be taken at any time, for example, at the batching station, on arrival at the construction site or after placement and compaction. To determine the air void parameters corresponding to those obtained on a core of the hardened concrete, the sample should be taken after final compaction. The procedure is non-destructive, however, because only a very small amount (20 ml) of concrete is removed and this can easily be immediately replaced.

A sample of the mortar fraction of the concrete is taken from a representative area of the concrete by inserting a wire cage into the concrete under vibration. This causes the mortar to enter the cage while excluding all aggregates larger than the wire spacing of 6 mm. A syringe is inserted into the mortar in the cage to withdraw a 20 ml sample for analysis.

The sample is injected from the syringe into the special liquid in the bottom of a riser column, illustrated schematically in Fig. 2, and the computer control is started. The computer immediately (i) sets the balance to zero, (ii) causes the mortar to be gently stirred for 30 s to release the air voids into the liquid and (iii) monitors the balance readings.

In the early stages of the measurement, the size distribution of bubbles arriving at the buoyancy recorder range from a few mm down to a few  $\mu\text{m}$  but, for each succeeding period, the maximum size of bubbles decreases as all the larger bubbles have already risen to the top of the column. This is illustrated schematically for four bubble sizes in Fig. 3 whereas, in practice all bubble sizes must be considered.

The measurement procedure continues for 25 min which has been demonstrated to be an appropriate time period to give air void parameters comparable to those obtained by the ASTM linear traverse method with acceptable accuracy (typically  $\pm 10\%$ ). While voids of diameter  $\leq 7\mu\text{m}$  will continue to rise after this period, neglecting them is found to have a negligible effect on the results.

### RESULTS

The total air content and the void size distribution of the sample are calculated from the measurements of weight change as a function of time. From these data, the following parameters are calculated: (1) the total air content; (2) the air content in voids  $< 3\text{mm}$ ,  $< 1\text{mm}$  and  $< 0.5\text{mm}$  as a volume % of both the concrete and the paste; (3) the specific surface and (4) the spacing factor.

Unlike the linear traverse method where the number of voids counted is of the order of a few hundred, the number of voids involved in the measurements by present method is of the order of millions. It is not, therefore, possible to measure the bubbles individually and present them in a detailed histogram for each 20  $\mu\text{m}$  size range as is the current practice for the linear traverse method. Instead, graphic representation of the results is accomplished by plots of the cumulative fraction of voids in ten different size ranges as a volume percentage of the concrete, and by the fraction of the voids in these size ranges as a percentage of the cement paste volume. Examples of these plots are given in Figs. 4 and 5. Because a specific volume of air represents a far greater number of voids of small diameter than it does of voids of large diameter, histogram in Fig. 5 is usually fairly flat rather than the exponentially decreasing form normally observed in the linear traverse histograms of "number of voids in different void size ranges".

### COMPARISON WITH ASTM 457 LINEAR TRAVERSE DATA

At Dansk Beton Teknik, five bars were cast from different concrete mixes. Five samples for the fresh concrete tests were taken at 10 cm intervals from each of the bars. After the bars were hardened, five impregnated, polished cut sections from each bar were prepared and analyzed according to the ASTM 457 procedure. The agreement between these two sets of data, illustrated in Fig. 6, is within  $\pm 10\%$ . Similar comparative studies are currently being carried out within the European Community and at Laval University, Quebec City, and the results of these investigations should be available within the next year.

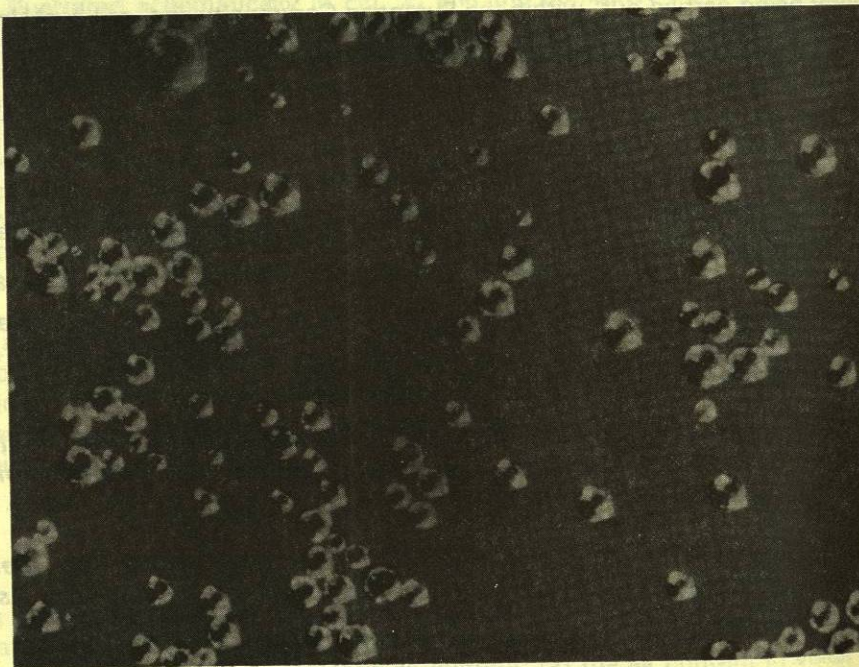
### REFERENCES

1. Powers, T.C., *The Physical Structure and Engineering Properties of Concrete*. 1958, The Portland Cement Association:
2. Eriksen, K., *Tilsætningstoffer (Admixtures)*, in *Beton Bogen (the Concrete Book)*, C.F.P.J. A.D. Herholdt P. Nepper-Christensen, A. Nielsen, Editor. 1985, Aalborg Portland: Aalborg. p. 328-341.
3. A.S.T.M. Standard Practice 457: *Microscopic Determination of Air-Void Content and Parameters of the Air-Void System in Hardened Concrete*, in *Annual Book of ASTM Standards*. 1992, ASTM: Philadelphia.
4. Jensen, B.J., Dansk Beton Teknik. A/S, U. S. Patent No. 4,967,588: *Method of Determining the Air Bubble Size Distribution in Fresh Concrete, an Analytical Assembly and a Sample taking Device for use herewith*. 1990.

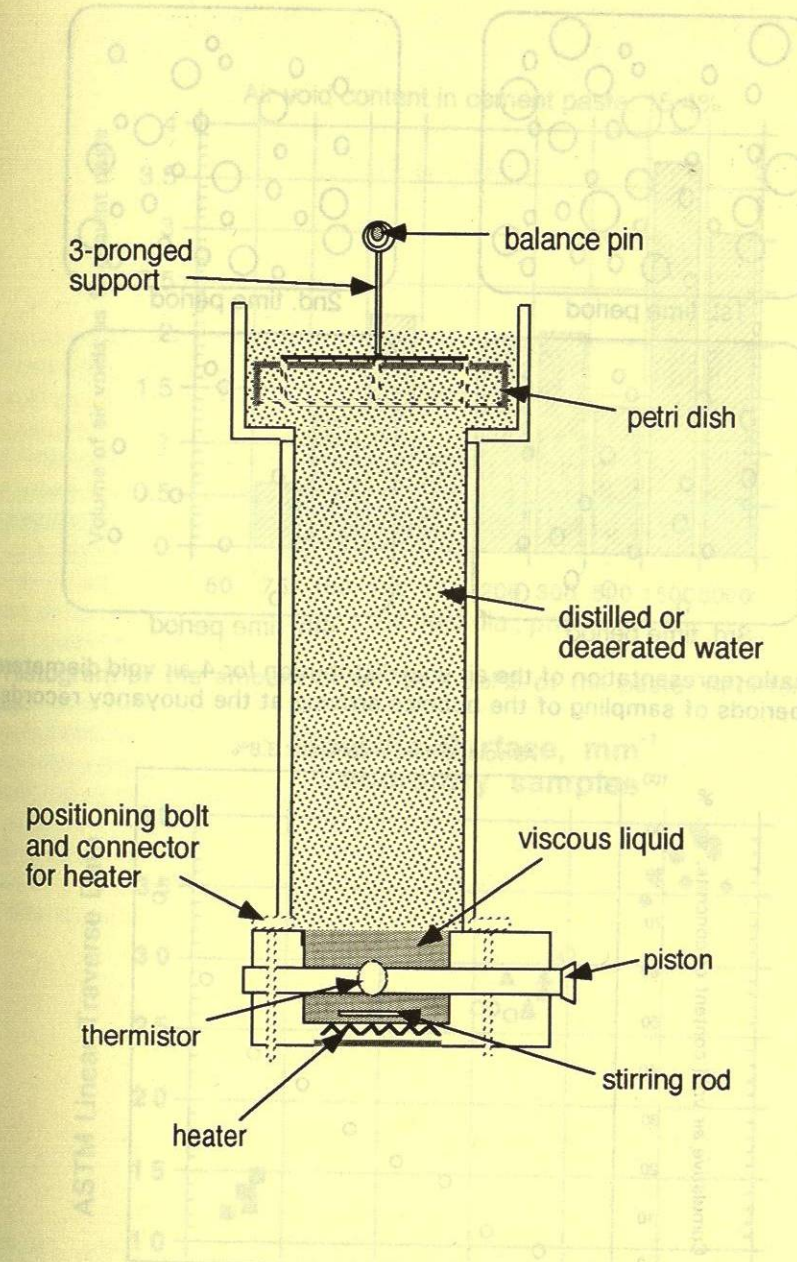




**Carolyn M. Hansson**, Professor and Head  
Materials and Metallurgical Engineering,  
Queen's University, Ontario, Canada.



**Fig. 1.** Typical distribution of bubbles obtained from air entrained concrete.



**Fig. 2.** Schematic representation of the riser column.



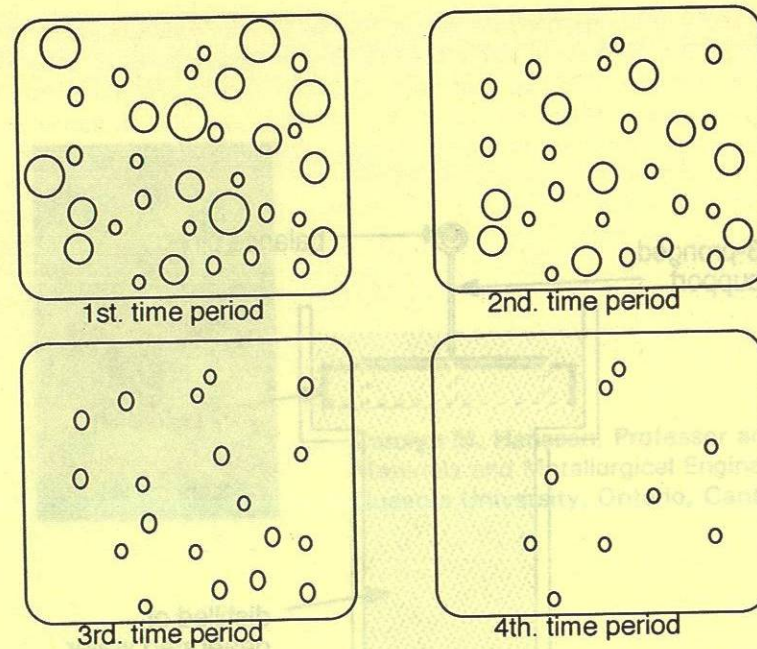


Fig. 3. Schematic representation of the air void distribution for 4 air void diameters in four different periods of sampling of the bubbles arriving at the buoyancy recorder.

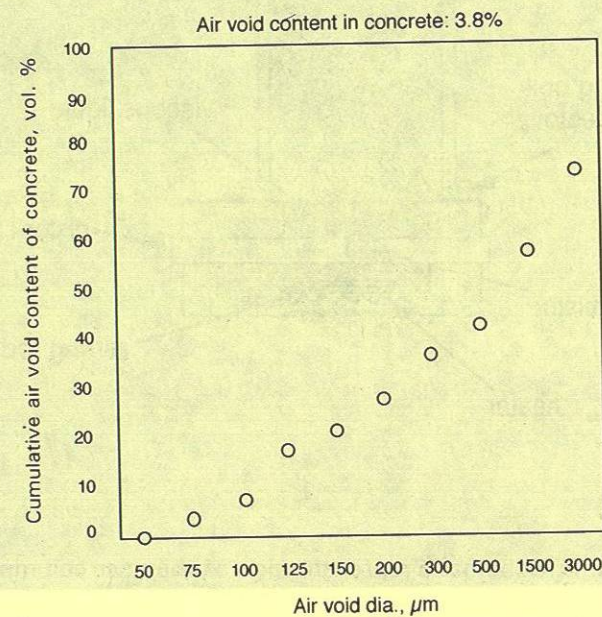


Fig. 4. Cumulative air void volume in concrete.

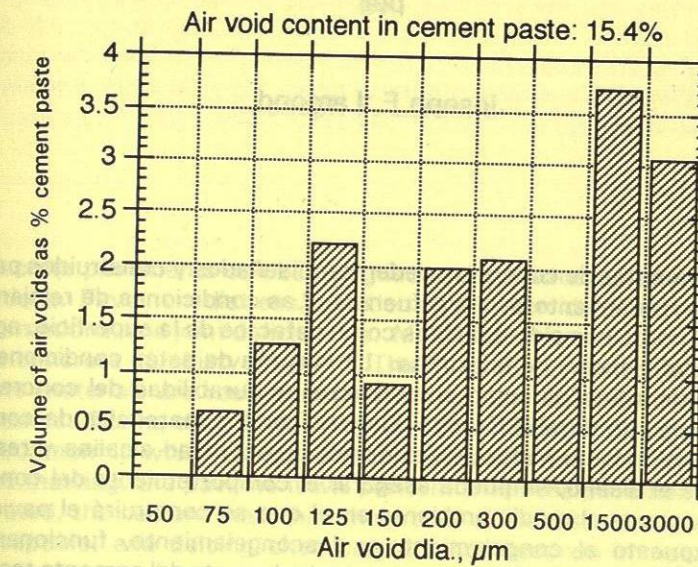


Fig. 5. Histogram of the amount of air (as a vol% of the paste) in different void size ranges.

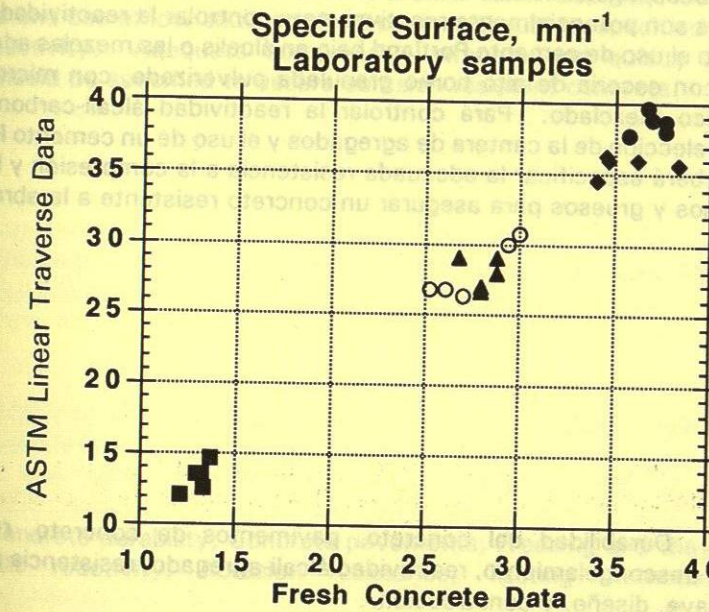


Fig. 6. Comparison of specific surfaces determined on the same laboratory concretes by the ASTM 457 procedure and the fresh concrete air void analysis techniques.