4th Middle East NDT Conference and Exhibition, Kingdom of Bahrain, Dec 2007
For all papers of this publication click: www.ndt.net/search/docs.php3?MainSource=57

EXAMINING CONCRETE CORES BY NON-DESTRUCTIVE TECHNIQUES

Sinan Caliskan*
EXPEC Advanced Research Center, Saudi Aramco, Dhahran, Saudi Arabia

ABSTRACT

Computed Tomography (CT) scanning has served as an important non-destructive research tool by providing two- and three-dimensional images particularly in medicine, biology and materials science. An example of its application in the area of materials is reported. Experimental study was carried out to investigate the effect of location within column element on the strength and porosity characteristics of concrete by using both destructive (strength test) and non-destructive techniques (CT scanning, ultrasonic pulse velocity and rebound hammer). Tests were conducted on the cores (100mm diameter and about 200mm long) obtained from 8.0m high with 0.5x0.5m cross-section of un-reinforced Fly Ash concrete column. The results indicate that the cores from the upper part of the column exhibited more porous structure and lower rebound hammer and compressive strength values compared to those of cored specimens obtained from the lower part of the column.

INTRODUCTION

Concrete is a heterogeneous material both at the micro and macro level due to the nature of its constituent materials, which are difficult to mix uniformly because of differences in the specific gravity of water, unhydrated cement particles and the aggregate. Furthermore, during the initial hardening process, water tends to rise inside concrete, known as bleeding. After the hardening process, the amount of accumulated water differs between top, middle and bottom of concrete element and the effect would be more pronounced in a vertical element, e.g. column and wall elements. Particularly at the very top, the amount of trapped water is anticipated to be relatively large (Hoshino, 1989).

The air content of concrete may vary between 0.2 to 10.5% depending on the variability of mix design, i.e. w/c ratio, fine and coarse aggregate types and content as well as the type and dosage of admixtures where they are used (Penttala, 2006). This implies that the constituent materials can play significant role in packing and hence the air content. Pores within concrete can also result from either hydration process or due to inadequate compaction. Engineering and durability properties of concrete are governed by internal structure, in particular by the pore system and porosity of concrete. The effect of pores smaller than 20 nm in diameter was found to be negligible (Sutan et al., 2002; Khatib and Mangat, 2003). Research by Sersale et al. (1991) showed that increasing the volume of the pores larger than 20 nm in diameter for mortar reduced the compressive strength from 60 MPa to 20 MPa. However, there is limited work on quantifying the influence of location within a concrete element on porosity and pore size distribution. Therefore, to examine the pore structure of concrete including their shapes, volumes, locations and distributions would be significant in analysing concrete. This would help to deal with structural problems associated with deteriorated concrete present in existing buildings and highway structure (Karihaloo and Jefferson, 2001).

Computed tomography (CT) allows non-destructive imaging, measuring and analyzing the pore structure and flow characteristics of engineering materials, e.g. rock and concrete. Scanning provides two- or three-dimensional (2-D or 3-D) images of the internal structures of samples, reflecting relative X-ray attenuation (function of the X-ray energy and the density and atomic number of the material being scanned). The high attenuation contrast between air

* Formerly in the University of Dundee, Dundee, United Kingdom

and other materials in samples allows direct imaging of individual pores and networks, in particular in a sufficiently high spatial resolution (Siddiqui 2001; Ketcham and Iturrino, 2005). CT scanning has been used as a non-destructive tool in a wide range of engineering including geological engineering (Siddiqui et al., 2006), mechanical engineering (Dastarac, 1999) materials science (Iovea et al., 1999) automotive and motorcycle industries (Flisch, 1999) and civil engineering (Karihaloo and Jefferson, 2001; Chotard et al., 2003). Specific fields of interest are porosity and flaw detection, fluid flow behaviour, analysis of failure, dimensional measurements of not accessible geometrical features, inspection of assemblies or statistical investigations of material properties as density distribution.

In this paper, an example application of CT scanning technique in engineering materials is demonstrated. In addition to the CT scanning, compressive strength as well as ultrasonic pulse velocity (UPV) and rebound hammer readings were carried out.

EXPERIMENTAL DETAILS

Materials and Mix Proportions

Un-reinforced column element of 8.0m high with cross section of 0.5x0.5m was constructed in open air using Fly Ash (FA) concrete. Concrete was discharged into the column element via a concrete pump. During the placing of fresh concrete into the column, vibration was applied using poker vibrator to achieve optimum compaction. The power and the duration of the vibration were kept constant throughout the filling of the column element. Properties of fresh concrete before the concrete pour by slump test (110 mm) and 28 days of compressive strength (32.5 MPa) were determined. Concrete contained 30% FA by mass of total cement content. Concrete mix proportions and the chemical properties of Portland cement and FA used in concretes are given in Tables 1 and 2, respectively.

Table 1 Mix proportions (kg) for 1m^3 of concrete used for the test.

Cement		Water	Aggregates			Superplasticizer
PC	FA		20mm	10mm	Sand	
248.5	106.5	185	800	400	670	0.25

Table 2 Bulk oxide chemical composition of cements.

Bulk Oxide, % by mass	Cement Type	
	PC	FA
SiO_2	21.0	52.3
Al_2O_3	4.9	25.8
Fe_2O_3	2.6	5.5
CaO	64.6	1.8
MgO	1.2	2.2
P_2O_5	nd	nd
TiO_2	nd	1.1
SO_3	3.3	0.7
K_2O	0.7	2.5
Na_2O	0.1	1.9
MnO	nd	nd
LOI, %	1.4	2.9

nd = non detected

Test Methods

After the formwork was removed in the following day of concrete placing, the column was taken down and rebound hammer readings were carried out at the heights of 1, 3, 5 and 7 m. To investigate the location effect on the strength and porosity of concrete within a column, cores of about 200mm long with 100mm diameter were taken from the lower and upper areas as shown in Figure 1. These samples were kept in the normal room temperature of 20 ^{o}C and relative humidity of 65% and tested at 90 days. Ultrasonic pulse velocity and compressive strength of concrete were determined and the cores were scanned by using Computed Tomography for porosity examinations.

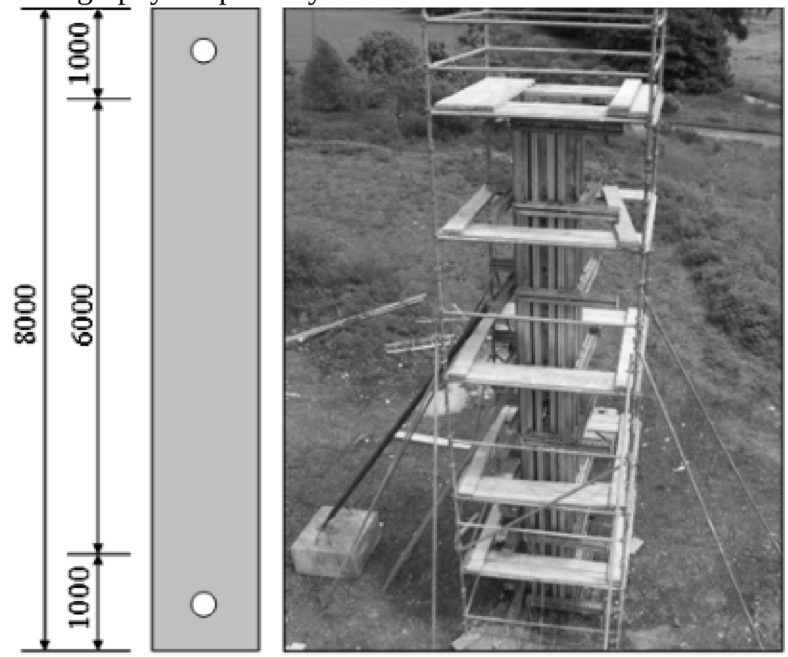


Figure 1 Locations of the cores (base and top) on 8.0 m column, (units are in mm),

Compressive strength and Ultrasonic Pulse Velocity (UPV)

After ensuring the flatness of both ends of the concrete cores, compressive strength and ultrasonic pulse velocity of cores (90 day) from the base and top part of column was determined.

CT scanning

CT scanning was performed using General Electric Light Speed Plus Multi Slice with helical scanning capability scanner at Ninewells Hospital in Dundee, UK (see Figures 2 and 3) on concrete cores to observe differences in internal structure with respect to their locations in column element. During the scanning, the examination table advances at a constant rate through the scanner gantry while the X-ray tube rotates continuously around the specimen, tracing a spiral path through the object. This spiral path gathers continuous data with no gaps between images. These scanners can collect up to 4 slices of data in a single rotation in 250 ms to 350 ms and reconstruct a 512 x 512-matrix image from millions of data points in less than a second. The output images are viewed in grey scale such that air appears black and most dense parts in the image appears as white, or they can be reversed.

The concrete cores were located on the CT table as a single specimen with the help of a u-shape sponge holder to avoid possible movement as shown in Figure 2. The exact positioning was ensured using laser positioning device. Before the scanning session started, series of trial scans were performed to achieve best possible images. The CT settings used during the scanning are given in Table 3. The samples were scanned constantly at 2.5mm pitch overlapping in the middle providing images of 1.25mm thickness. A total of 160 to 200 2-D images were obtained from each specimen depending on the specimen length. These 2-D images can be processed to provide 3-D representation of cored specimens. The images were analysed by using the 3D-Doctor software.

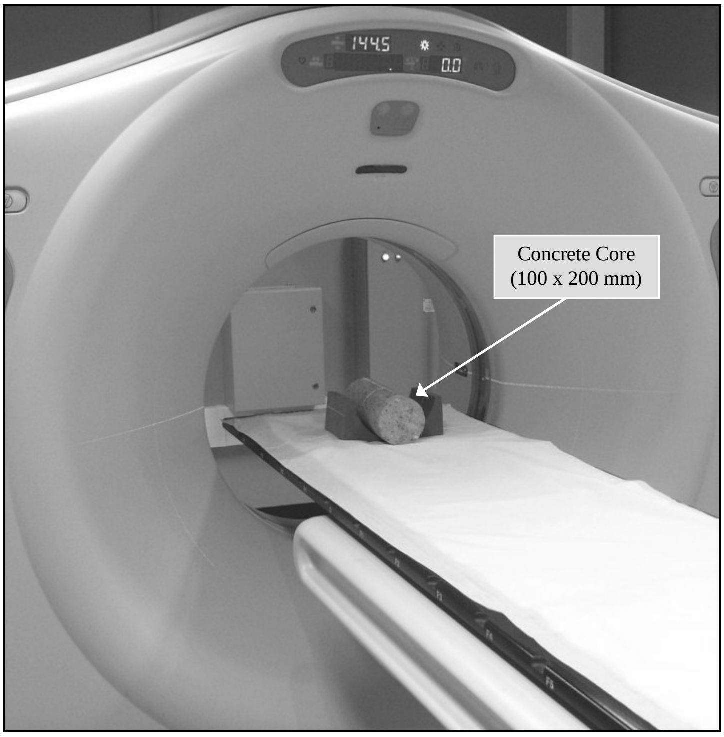


Figure 2 A general view of the CT machine during concrete core scanning.

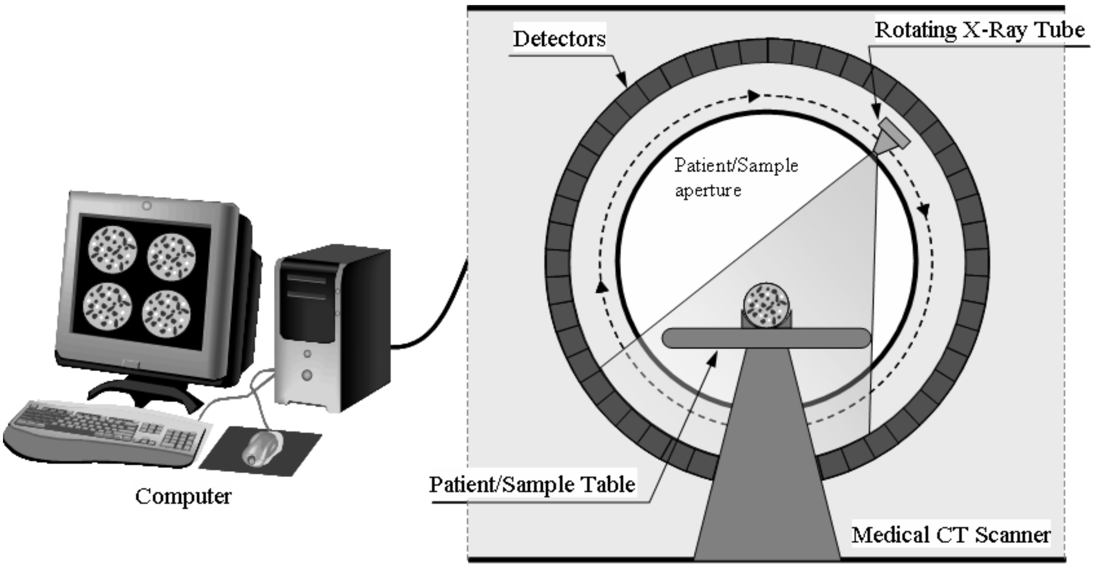


Figure 3 Schematic explanation of how a CT scanning system works.

Table 3 Settings used for CT scanning of cores.

Helical Point	0.6 sec
Slice Thickness	2.5 mm (interval 1.25 mm)
Scan mode	1.5 – 1 (pitch)
Speed	15 mm/rotation
Exposure	120 kW and 380 mA

Recon Matrix	512 x 512
Field of view	173 mm

Estimation of porosity

The data obtained from the CT scanning study was analysed using the 3D-Doctor software. Digital 3-D concrete cores were reconstructed by using 2-D CT images as shown in Figure 4. It is shown in Figure 4 that air pockets are in black, cement matrix is in dark grey and the aggregate particles are in light grey or in white in some cases. Furthermore, by eliminating the aggregate and cement paste a 3D pore network for each concrete core was produced (Figure 5). By the analyses carried out using the software, the total volume of air and the over all volume of the cores were determined for the concrete cores obtained from both lower and upper areas of the column.

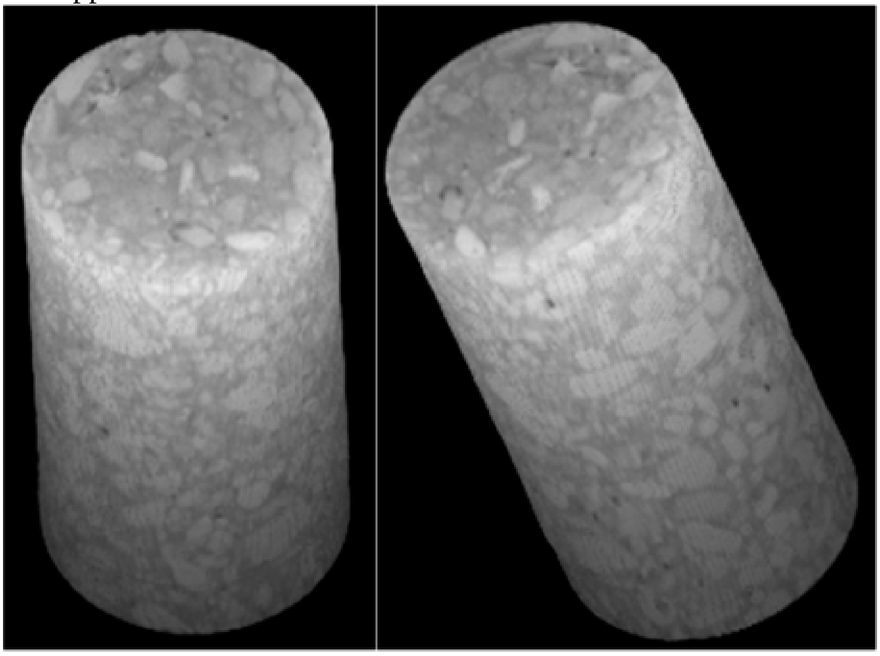
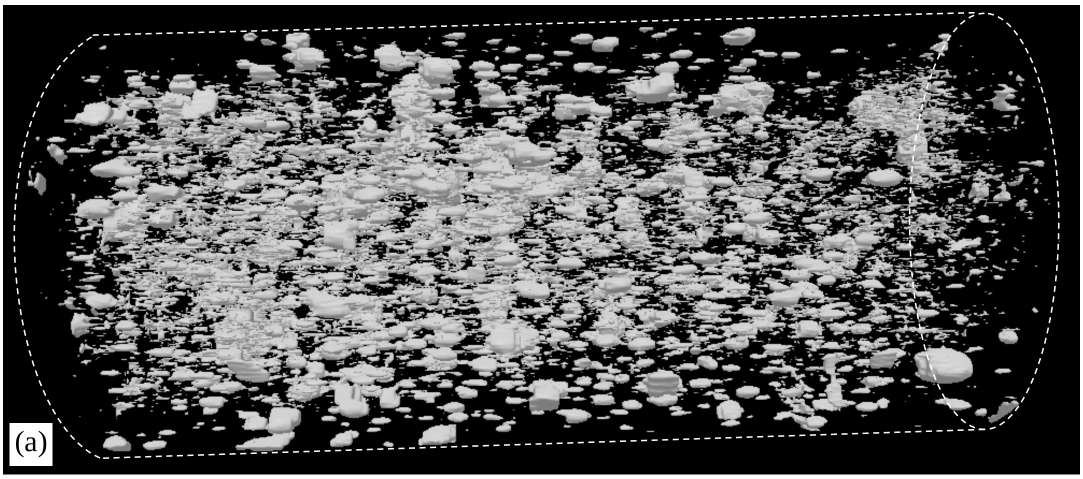


Figure 4 Reconstructed 3-D view of concrete core specimen (base)



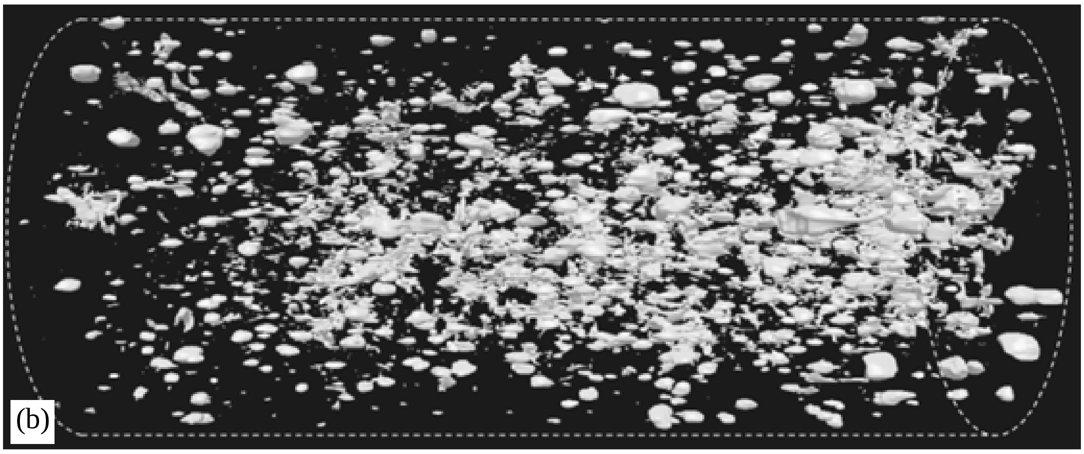


Figure 5 Structure of air pores within the scanned sample, a) top, b) base

RESULTS AND DISCUSSION

Compressive Strength and Ultrasonic Pulse Velocity (UPV)

Compressive strength and the UPV results of concrete cores from different heights at 90 days are shown in Figures 6a and b, respectively. It is indicated that the specimen from the lower part of the column provided higher compressive strength and ultrasonic pulse velocity values than those of specimen from the upper areas of the column. The difference between the upper and lower parts of FA column indicates the quality and the structural variations between different locations on column. As the concrete was discharged from a single batch, and that the vibration was applied equally, i.e. similar duration and power, it is likely that the variation was due to higher self weight over the lower areas the column. This may indicate that the lower areas in column element achieve better packing.

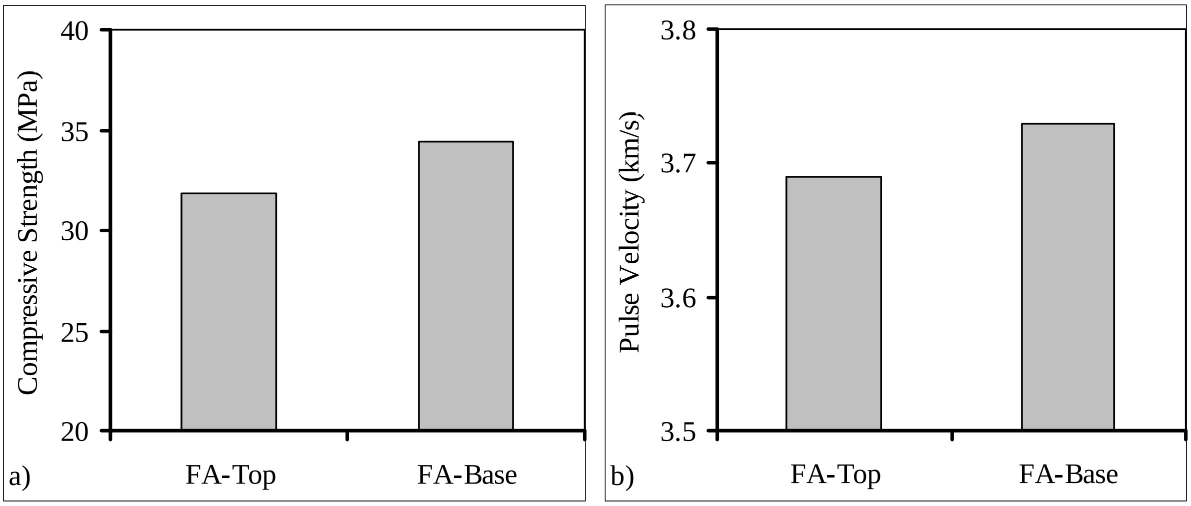


Figure 6 a) Compressive strengths and b) UPV values of specimens from different locations

Rebound Hammer Values

Figure 7 shows the results of rebound hammer readings at various heights of the column element. The figure indicates that the surface hardness through the rebound hammer readings were higher at the lower end of the column and it was gradually declined towards the higher end. The difference between the values of the lower end and the higher end was about 2. This finding is in agreement with those of compressive strength and UPV results of the concrete cores, i.e. a better concrete is obtained at the lower areas of the column than that of upper areas.

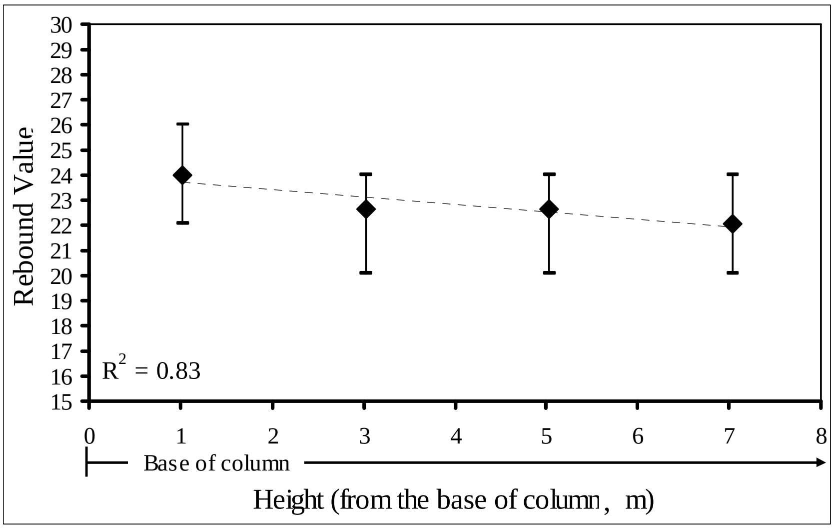


Figure 7 Variation of rebound values along the column height

Estimation of Porosity

Relationship between porosity (defined as the total volume of the overall empty space, expressed as a percentage of the overall volume of the concrete) and the location on column element is examined. The calculated porosity values for the concrete core specimens are given in Figures 8a and b. It is shown that the upper part of the column contained 1.75% air whilst the lower part of the column contained 1.12% air. This indicates that at the lower levels of the column, in addition to the vibration self weight of concrete further helped the concrete to form denser structure compared to the upper areas. This finding is again in line with the results of compressive strength and the rebound hammer values.

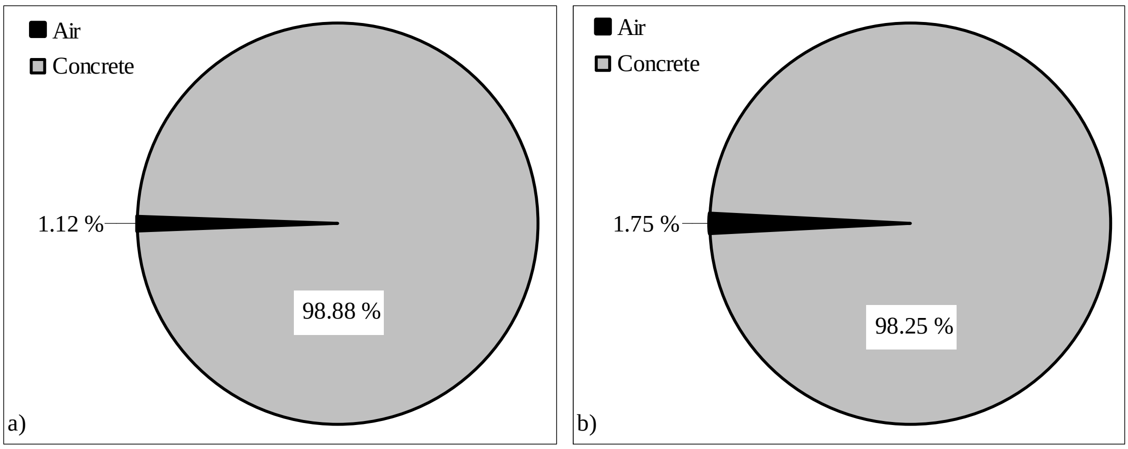


Figure 8 Percentage of volumes of concrete and air, a) base and b) top.

CONCLUSIONS

This study was carried out to investigate the influence of different locations within column elements on the hardened structure of FA concrete. From the study the following conclusions may be drawn:

- Compressive strength, UPV values and rebound hammer results were varied between upper and lower levels of column (always higher at the lower areas) indicating the variation in concrete quality along the height of the column.
- The porosity of the lower level was smaller than that at the upper level of the column indicating the further packing at the lower level by the help of self weight.

- It is shown by this study that to examine the internal structure of cement-based materials, e.g. concrete porosity, CT scanning can be used successfully as a non-destructive experimental tool in particular when combined with relevant software.

REFERENCES

1. Chotard T. J., Boncoeur-Martel M. P., Smith A., Dupuy J. P., Gault C., Application of X-ray Computed Tomography to characterise the early hydration of calcium aluminate cement, *Cement and Concrete Comp*, V. 25, 2003, pp. 145 - 152
2. Dastarac D., Industrial Computed Tomography: Control and digitalisation, in Proceeding of International Symposium on Computerized Tomography for Industrial Applications and Image Processing in Radiology, Berlin, Germany, V. 4, March 15 – 17, 1999, pp. 4-12
3. Flisch A., Industrial Computed Tomography in Reverse Engineering Applications", in International Symposium on Computerized Tomography for Industrial Applications and Image Processing in Radiology, Berlin, Germany, V. 4, March 15 – 17, 1999
4. Hoshino M., Relationship between bleeding, coarse aggregate, and specimen height. *ACI Materials J*, March – April; V. 86 (2), 1989, pp. 185 - 190
5. Iovea M., Georgescu G. H., Rizescu C., Chitescu P., Some aspects concerning the 2d and 3d Computerized Tomography applied in non-destructive testing", in Proceeding of International Symposium on Computerized Tomography for Industrial Applications and Image Processing in Radiology, Berlin**,** Germany, V. 4, March 15 – 17, 1999, pp. 4 -10
6. Karihaloo B. L., Jefferson A. D., Looking into concrete, *Magazine of Concrete Research*, V. 53 (2), 2001, pp. 135 – 147
7. Ketcham R. A. and Iturrino G. J., Nondestructive high-resolution visualization and measurement of anisotropic effective porosity in complex lithologies using high-resolution X-ray computed tomography, *Journal of Hydrology*, V. 302, 2005, pp. 92 - 106
8. Khatib J. M., Mangat P. S., Porosity of cement paste cured at 45 _C as a function of location relative to casting position, *Cement & Concrete Composites*, V. 25, 2003, pp. 97 - 108
9. Penttala V., Surface and internal deterioration of concrete due to saline and non-saline freeze–thaw loads, *Cement and Concrete Research*, V.36 (5), 2006, pp. 921 - 928]
10. Sersale R., Cioffi R., Frigione G., Zenone F., Relationship between gypsum content, porosity and strength of cement, *Cement and concrete Research*, V. 21 (1), 1991, pp. 120 - 126
11. Siddiqui S., Application of Computerized Tomography in Core Analysis at Saudi Aramco, *Saudi Aramco Journal of Technology*, Winter 2000-2001, pp. 2 - 14.
12. Siddiqui S., Grader A. S., Touati M., Loermans A. M. and Funk J. J., Extracting Reliable Density and Porosity Data from Cuttings, *Saudi Aramco Journal of Technology*, Summer 2006, pp. 38-53.
13. Sutan N. M., Hamdan S., Jin E. C. C., The influence of porosity to the accuracy of ultrasound pulse velocity method, *The e-Journal of Nondestructive Testing*, http://www.ndt.net/, 7 (11), 2002