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Finite Element Modeling of Concrete Based on Quantitative Computed Tomography (QCT)

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CorRlab

Corrosion Research Laboratory

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INTRODUCTION

Models have been used before to predict the mechanical and transport behavior of concrete. In most of these studies, aggregates were considered either circle or sphere and the impact of the aggregates geometry and in-homogeneities in concrete structure is ignored.

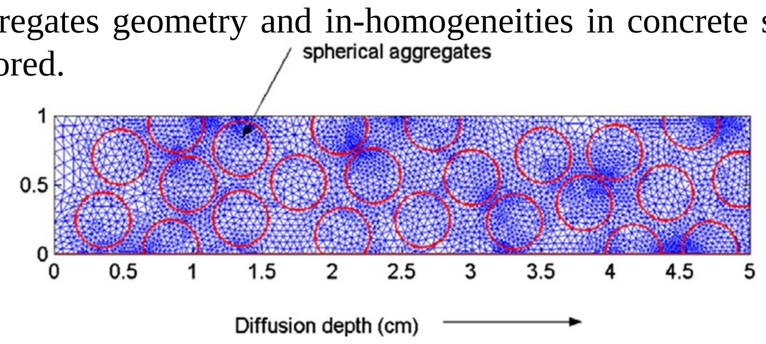

Figure 1. Model of concrete for diffusion with circular aggregates[1].

[1]Y. Zeng, "Modeling of chloride diffusion in hetero-structured concretes by finite element method. "Cement and Concrete Composite," 2007. 29(7): p. 559–565.

As Figure 1. shows, a rectangular 100 by 10 mm plane concrete body with its surface exposed to a chloride containing medium, which aggregates modeled as circular shaped.

L. Liu and his colleagues made a 3D model of the microstructure of hydrated cement to investigate internal damage of saturated cement paste due to ice crystallization pressure during freezing, this model is shown in Figure 2. which aggregates modeled as non real spherical shapes.

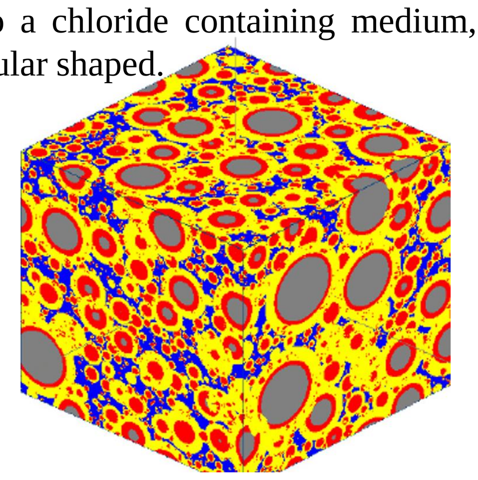

Figure 2. 3D image of hydrated cement paste[2]

[2]L. Liu, G. Ye, E. Schlangen, H. Chen, Z. Qian, W. Sun, and K. van Breugel, "Modeling of the internal damage of saturated cement paste due to ice crystallization pressure during freezing." Cement and Concrete Composites, 2011. 33(5): p. 562–571.

Failure analysis model is illustrated in Figure. 3 by S. Kim and his colleagues, in this 3-D model the stress–strain curve obtained. As can be seen in this Figure, the 3-D analysis gives a tensile strength. Different aggregate distribution has been considered but as a spherical shaped.

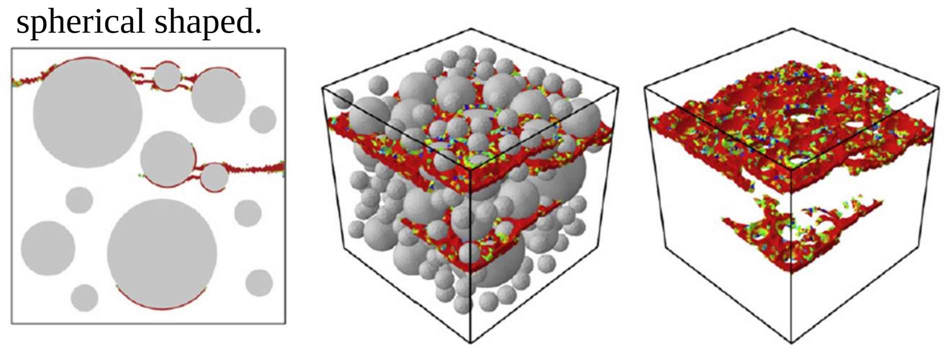

Figure 3. 3-D tensile damage propagation of cementitious composites[3].

[3]Sun-Myung Kim, Rashid K. Abu Al-Rub, "Meso-scale computational modeling of the plastic-damage response of cementitious composites." Cement and Concrete Research, 2011. Vol. 41:339-358.

But as shown in Figure 4. in reality aggregates have no simplified geometrical shapes and this simplification will reduce the precision of the analysis and may cause some error.

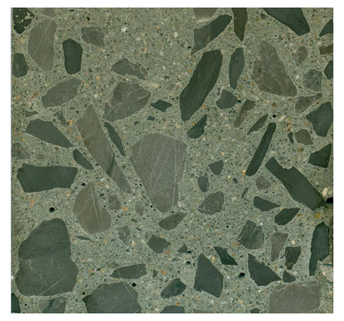

Figure 4. Real aggregates have non regular shape

OBJECTIVES

The objective of this study is to develop a novel method for accurate prediction of the mechanical behaviorof concrete using quantitative computed tomography (QCT)-based finite element analysis. Concrete cylinders were cast and cured for 28 days. The QCT scans were carried out on the samples using a clinical CT scanner. An image processing method was applied to detect aggregates, paste content and the air voids. The distribution of each phase then calculated in each image slice (2D) and in the bulk material (3D). The processed QCT images were directly converted into voxel-based 3D FE models for linear and nonlinear analyses. The FE models were generated by conversion of each voxel into an 8-noded brick element. Air void content of the cylinders (2D and 3D) was determined. In addition, the aggregates content was estimated using the image analysis. In both cases, the results obtained by the image analysis and the actual measurement and ASTM method are in very good agreement.

SAMPLE PREPARATION

Table 1. Mixture Proportion

Materials	Specific Gravity	Amount (Lbs./yd^3)	Volume (ft^3/yd^3)	Batch Volume (ft^3)	Percentage
Cement (Type I)	3.15	913.84	4.65	4.65	
Water	1	383.81	6.15	6.15	W/C 0.42
Fine Aggregate	2.46	1036.15	6.75	6.75	25%
Coarse Aggregate	2.48	1462.41	9.45	9.45	35%

X-ray IMAGING

As shown in Figure 5., X-Ray attenuates when passing through an object. Attenuation is following by Beer's law: $I(x) = I_0 e^{-\mu x}$

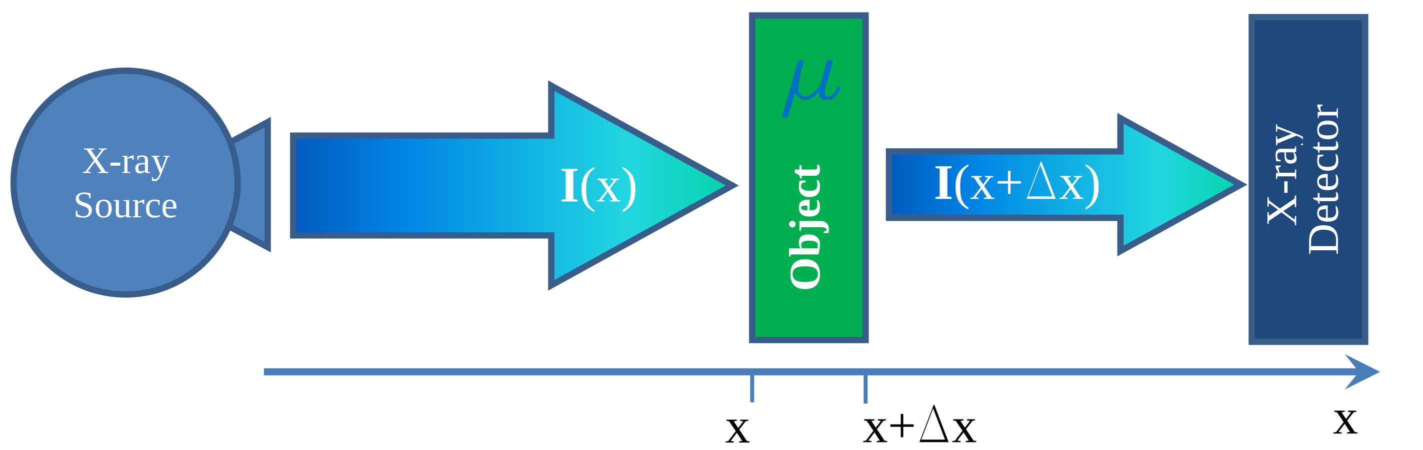

Figure 5. X-ray attenuation mathematical model while running through a homogeneous object with constant attenuation μ

As Figure 6. shows, a rotating X-ray source together with sample translation provides cross-sectional or slice images of 3-D objects. The portion of the sensors opposite the source collect the X-ray energy that pass through the object.

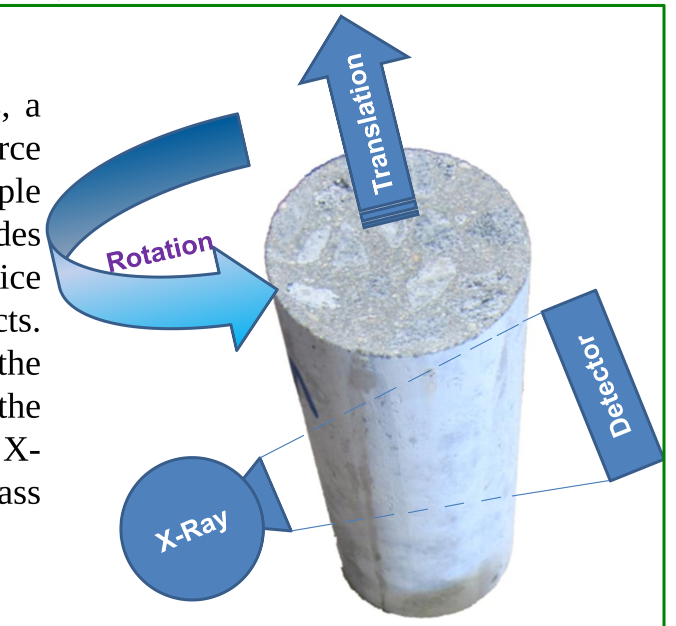

Figure 6. Three dimensional X-ray tomography

IMAGING PROCEDURE

The following steps are used for imaging and image processing:

The QCT scans were carried out on concrete samples using a clinical scanner (Figure 8.). The X-ray parameters were set at 120keV and 200mA. Each voxel has the size of 0.25×0.25 mm/pixel resolution, and 1mm slice thickness. This set up provides approximately 200 sliced pictures for each sample. Figure 9 shows one of the slices.

Figure 7. Concrete cylinder

Figure 8. QCT imaging device (Phillips MX 8000)

Clinical scanner at Oconee Medical Center

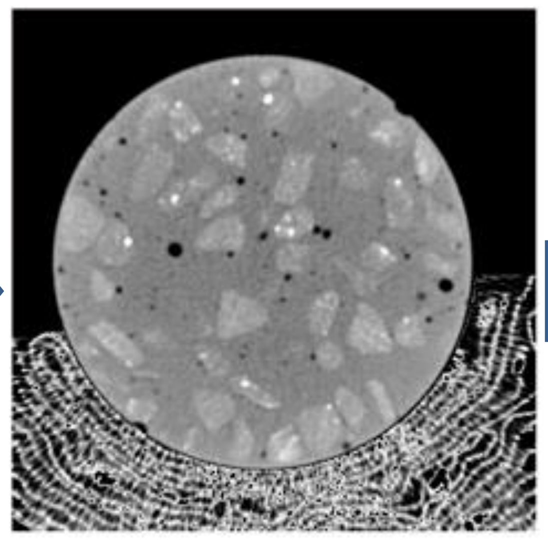

Figure 9. QCT raw image with surrounding

The unnecessary portions of image shown in Figure 9, eliminated and the result is shown in Figure10.

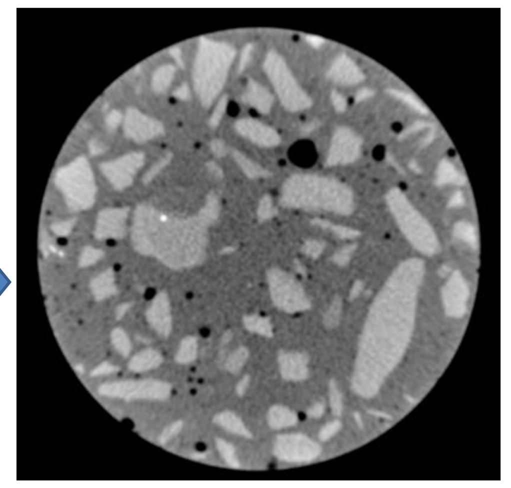

Figure 10. Raw image with eliminated surrounding

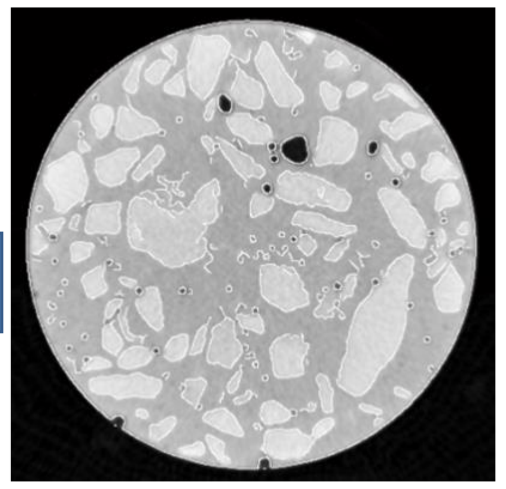

Figure 11. Coarse aggregates and void discrimination (primary stage)

Edge of coarse aggregates can't be detected completely and are rough because of weakness in some parts of image.

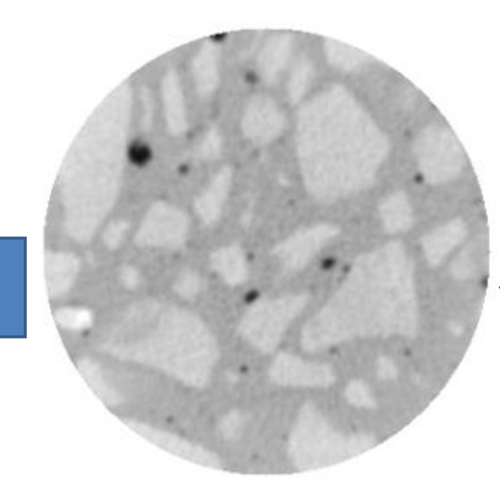

Figure 12. QCT image before applying filter

Weak portions of coarse aggregate can be seen in Figure 12

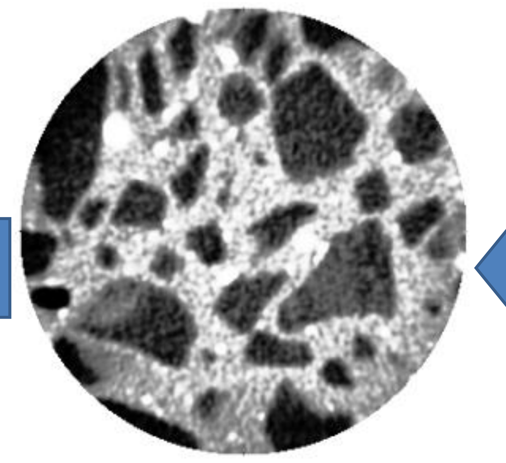

Figure 13. QCT image after applying filter

After applying filters, intensity of weak parts were improved

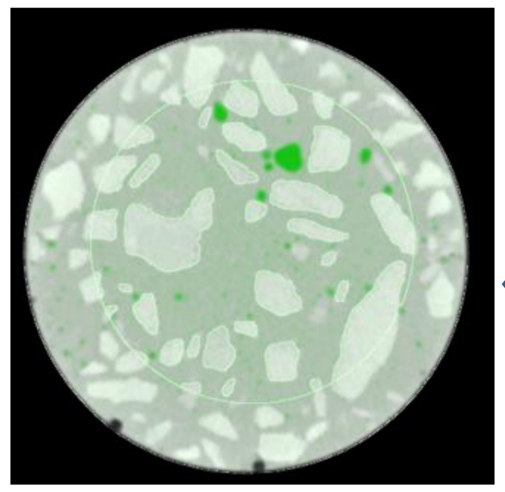

Figure 14. Coarse aggregates and void discrimination (final stage)

Coarse aggregates and air voids discriminated completely with smoothed edges

FINITE ELEMENT MODELING

QCT-based finite element models of concrete specimens have been created by voxel-based method. In this method, the geometry is obtained directly from the images without using any surfaces or solid bodies and the finite element mesh is developed by assigning hexahedral elements that each encloses a predefined cubic volume of image voxels. Element sizes on the order of 0.25mm x 0.25mm x 1 mm have been used for the voxel-based method.

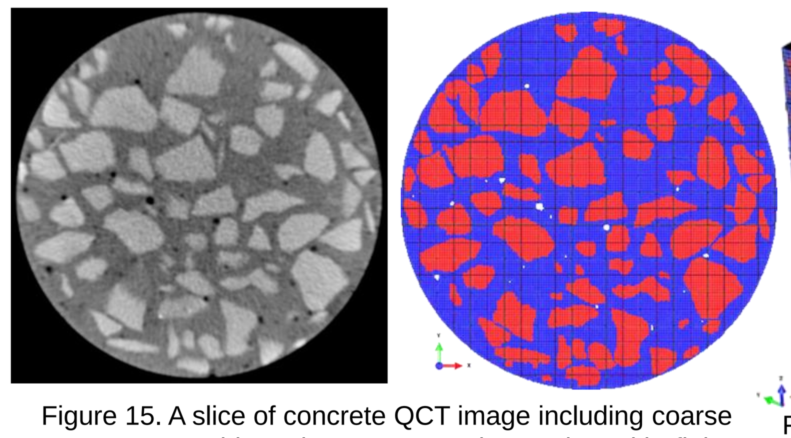

Figure 15. A slice of concrete QCT image including coarse aggregates, voids and concrete matrix together with finite element model corresponding to the same slice.

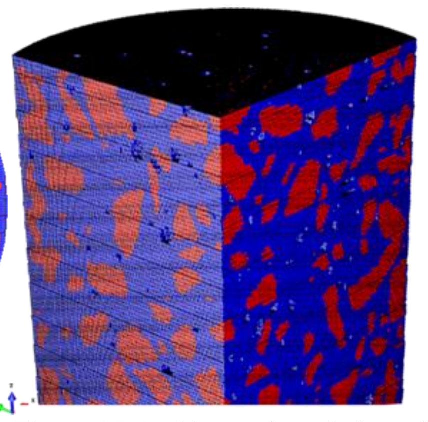

Figure 16. Inside sectioned view of 3D finite element model of concrete sample in Abaqus.

A slice of concrete QCT image is shown in Figure 15. including coarse aggregates in red, voids in white and concrete matrix in blue color. 3D FEM of whole concrete sample includes 26 million elements and 27 million nodes shown in Figure 16. Due to this high amount of elements using personal computer was not applicable. Therefore, Clemson high performance computing (HPC) resource has been used. .

RESULTS AND CONCLUSIONS

All processed images assembled slice by slice to make a three dimensional model. Using this sectioned view, aggregate and void distribution inside concrete could be investigated in order to find if there are any defects or segregation. One of the QCT applications is shown in Figure 17. It illustrates a 3-D model indicating aggregates in light gray, cement matrix in dark gray and air voids in red color inside it.

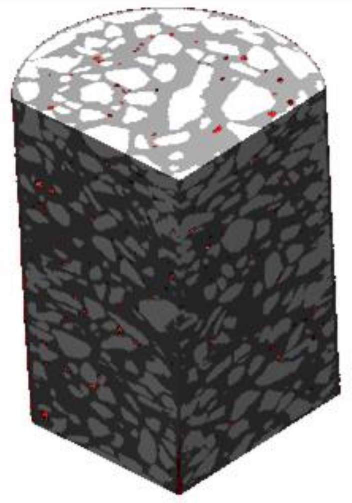

Figure 17. Inside sectioned view of 3D model of concrete sample.

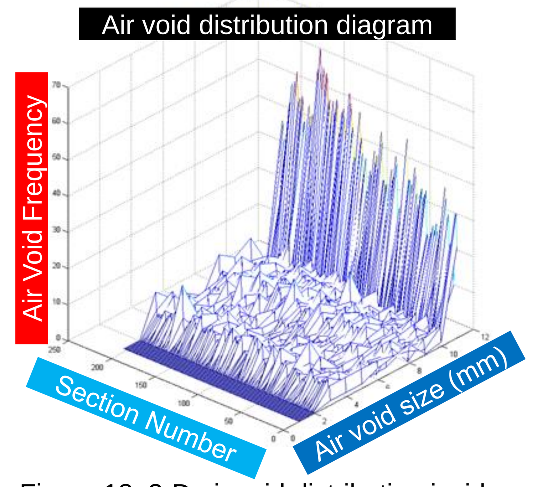

Figure 18. 3-D air void distribution inside the concrete sample.

ASTM C457 to measure air void content takes too much time, give total air void amount and its precision is operator dependent but this imaging techniques as shown in Figure 18 not only calculates the total air void in less than 5 min but also gives the air void distribution together with their size classification.

As shown in Figure 19. The distribution of coarse aggregates has been calculated for each QCT slices. The mean value of aggregate fraction is in good agreement with that amount in mixture design.

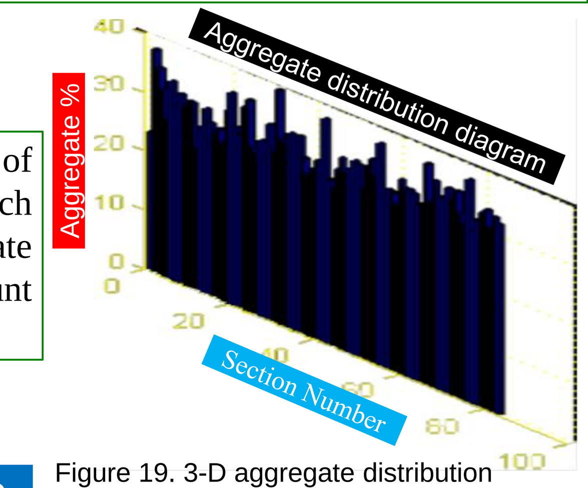

Figure 19. 3-D aggregate distribution

GOALS AND FUTURE WORKS

- Air void assessment
- Aggregate content assessment
- Mechanical performance assessment
- Moisture ingress modeling
- Chloride diffusion modeling
- Corrosion prediction and modeling