46th Annual Review of Progress
in Quantitative Nondestructive Evaluation
QNDE2019
July 14-19, 2019, Portland, OR, USA

QNDE2019-6975

X-RAY MICROTOMOGRAPHY SYSTEM APPLIED IN CHARACTERIZATION OF LIGHTWEIGHT CONCRETE STRUCTURES

Luan F. Bastos, Olga M. O. de Araújo, Alessandra S. Machado
Nuclear instrumentation laboratory, Federal University of Rio de Janeiro
Rio de Janeiro, Brazil

Davi F. Oliveira[1], Ricardo T. Lopes
NUCLEAR INSTRUMENTATION LABORATORY, FEDERAL UNIVERSITY OF RIO DE JANEIRO
Rio de Janeiro, Brazil

[1]Contact author: davi@lin.ufrj.br

ABSTRACT

Microtomography is a powerful non-destructive method that allows the visualization of the internal structure of the object and makes possible to generate trust internal graphic models of the object. Concrete is a mixture widely used in the construction industry due to the union between its mechanical properties with the low cost for its production. The application of X-ray microtomography in lightweight concrete structures allows the visualization of the layout and formation of existing internal structures in it. It was possible to identify the presence of ethyl vinyl acetate (EVA) and piaçava fibers in the internal structure of the samples and to classify the high density aggregates according to the ASTM C125-18 standard.

Keywords: X-ray microtomography, lightweight concrete structures, internal structure

NOMENCLATURE

EVA	ethyl vinyl acetate
microCT	computed microtomography
ROI	region of interest
VOI	volume of interest

1. INTRODUCTION

Concrete is a composite material that consists essentially of a binding medium within which are embedded particles or fragments of aggregate. Aggregates are a granular material, such as sand, gravel, crushed stone, used with a cementing medium to form hydraulic-cement or mortar [1-3].

The strength of mortar or concrete depends on the cohesion of the cement paste, on its adhesion to the aggregate particles, and to a certain extent on the strength of the aggregate itself [4-6], so the study of the concrete is very important to understand how its components work during the stresses.

In this study, acquisition, reconstruction, binarization and analysis of five lightweight concrete samples were performed through the microCT technique in order to characterize the internal elements and classify the gravel, EVA and *piaçava* fibers according to ASTM C125-18, as well as to determine the porosity of the samples.

2. MATERIALS AND METHODS

2.1 Samples

The samples used in this study consist in five plugs with 30 mm of height and 25 mm of diameter extracted from concrete samples. It was used a 20 MPa concrete and a water cementing rate of 0.62. The quantity of each element used in the concrete samples can be seen at table 1.

TABLE 1: QUANTITY OF THE ELEMENTS USED IN THE LIGHTWEIGHT CONCRETE SAMPLES

Sample	Cement (kg)	Sand (kg)	Gravel (kg)	Water (L)	EVA (kg)	*Piaçava* fibers (kg)
Y1	10.64	18.05	36.09	6.60	-	-
X1	10.64	18.05	30.68	6.60	0.89	0.36
X2	10.64	18.05	27.07	6.60	1.49	0.36
X3	10.64	18.05	30.68	6.60	0.61	0.36
X4	10.64	18.05	30.68	6.60	0.89	0.72

2.2 Microtomography System

To realize this study, the X-ray microtomography system (Skyscan-Bruker model 1173) was used. That is a benchtop microtomography system with a minimum image pixel size of 5 µm. The microfocus X-ray source can operate with a maximum voltage of 130 kV and maximum power of 8 W.

Experiments were executed with following parameter: 100 kV, 80 µA, 8 W, rotation step of 0.50˚, 1.0 mm aluminum filter and 2240 x 2240 matrix of pixels. The image processing was performed using the software of the manufacturer.

2.3 Image Processing

Reconstruction of images was performed with software from the system manufacturer, InstaRecon®. The software allowed the correction of the following parameters: Smoothing, Misalignment compensation, Beam hardening and Ring artifacts.

CTAn, v. 1.18.4.0, was the software used for binarization and analysis of the data. CTAn defined the Volume of Interest (VOI) by adding and adjusting the region of interest (ROI) set in each slice. The use of morphological operations such as despeckle, closing, dilate and erosion was essential to study the physical properties for aggregates, EVA and *piaçava* fibers. Individual Objects Analysis and 2D Analysis Results were the functions used in the analysis. Table 2 shows the defined VOI for each sample.

TABLE 2: VOLUME OF INTEREST OF EACH SAMPLE ANALYZED

Sample	Y1	X1	X2	X3	X4
Volume (mm^3)	10048.38	7353.77	7125.51	6635.14	6069.66

AvizoFire, v. 8.1.1.0, was the software used to create the 3D models. It was necessary to use Connected Components functions before making the graphic models for aggregates, *piaçava* fibers and for pores.

3. RESULTS AND DISCUSSION

Tables 3 and 4 show the quantity of coarse and fine aggregates, respectively, according to the ASTM C125-18 classification. Table 5 shows the ratio of all aggregates volume to the total volume.

TABLE 3: COARSE AGGREGATES IN THE SAMPLES CLASSIFIED ACCORDING TO ASTM C125-18

Sample	Y1	X1	X2	X3	X4
4.75-9.5 mm	9	0	4	2	1
9.5-19 mm	2	2	1	1	2
< 19 mm	0	0	0	0	0
Total	11	2	5	3	3

TABLE 4: FINE AGGREGATES IN THE SAMPLES CLASSIFIED ACCORDING TO ASTM C125-18

Sample	Y1	X1	X2	X3	X4
0.15-0.3 mm	62	221	0	3	7
0.3-0.6 mm	140	178	381	11	3
0.6-1.18 mm	17	12	172	12	3
1.18-2.36 mm	4	7	11	6	5
2.36-4.75 mm	6	6	4	4	5
Total	229	424	568	36	23

TABLE 5: AGGREGATES RATIO FOR EACH SAMPLE

Samples	Y1	X1	X2	X3	X4
Concentration (%)	39.51	32.37	33.77	37.24	46.84

Y1 was the control sample and the one that had more coarse aggregates. X3 and X4 had fewer fine aggregates than the others. Analyzing the volume occupied by aggregates in the samples, it was possible to notice that X4 has the higher percentage, even presenting fewer aggregates than the others; it was the only one with more than 40%. X1 was the one with less percentage of all of the samples. These results can be explained by the heterogeneity of concrete and variation of the volume, which was determined by the volume of interest.

The 3D graphics models show the distribution of aggregates in the sample. Figure 1 shows the 3D models and it is possible to notice that Y1 has lots of coarse aggregates, while X2 has lots of fine aggregates.

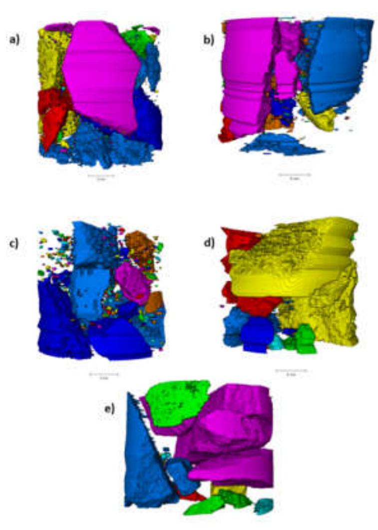

FIGURE 1: 3D GRAPHICS MODELS FOR AGGREGATES: a) Y1, b) X1, c) X2, d) X3 and e) X4

Piaçava fiber was analyzed and classification like light aggregate for the samples. Table 6 shows the classification for the fiber as an aggregate and table 7 shows the ratio of the fibers' volume.

TABLE 6: *PIAÇAVA* FIBER CLASSIFIED ACCORDING TO ASTM C125-18

Sample	X1	X2	X3	X4
0.15-0.3 mm	199	0	30	0
0.3-0.6 mm	64	125	204	2
0.6-1.18 mm	33	22	128	16
1.18-2.36 mm	8	6	29	10
2.36-4.75 mm	1	2	2	4
Total	305	155	393	32

TABLE 7: *PIAÇAVA* FIBERS RATIO FOR EACH SAMPLE

Samples	X1	X2	X3	X4
Concentration (%)	0.66	1.26	2.10	1.76

X3 is the sample that has the greater amount of fibers and the grater ratio of them. X1 is the second one, but it is the one with the lower ratio. This can be explained when the classification according to ASTM C125-18 is analyzed, since these objects are in the lower size range for X1.

X4 presents just 32 fibers, but the second ratio. This can be explained, like for X1, when we analyze in each interval the particles are.

Figure 2 presents the 3D graphics models that show the distribution of fibers in the samples. The fibers of samples X1 and X4 are more preserved than for X2 and X3. For the sample X2 the fibers are concentrated in the edges and X3 presents a more homogeneous distribution, even with fibers that not present a good conservation.

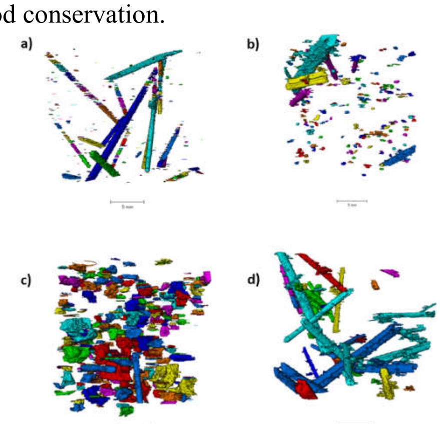

FIGURE 2: 3D GRAPHICS MODELS FOR PIAÇAVA FIBERS: a) X1, b) X2, c) X3 and d) X4

EVA was analyzed and the ratio of its volume is presented at table 8.

TABLE 8: EVA RATIO FOR EACH SAMPLE

Samples	X1	X2	X3	X4
Concentration (%)	10.98	17.28	6.65	7.17

X1 and X2 are the samples with the higher ratio of EVA, while for the samples X3 and X4, this ratio is much lower than the others. If we analyze the ratio of *piaçava* fibers and compare with the EVA, it is possible to note that the samples that presents higher ratio for the fibers presented the lowest values for EVA and vice versa.

The porosity for the samples is shown in table 9. The porosity for the sample Y1 was lower than the others. It was expected, since it does not have *piaçava* fibers and EVA in its composition. 3D graphics models for the pores are presented in figure 3. The distribution of pores is higher in the center of the samples.

TABLE 9: POROSITY

Samples	Y1	X1	X2	X3	X4
Porosity (%)	1.09	2.46	3.49	3.83	2.53

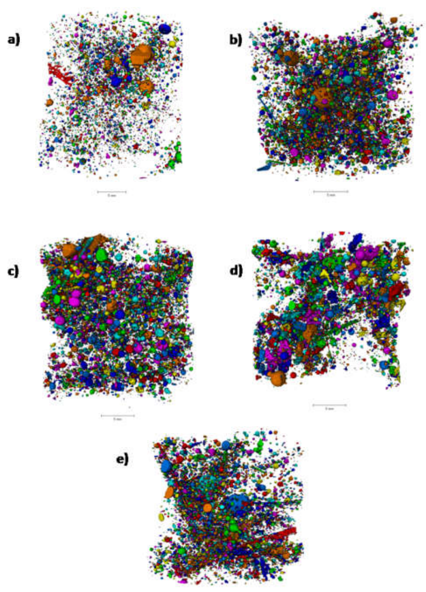

FIGURE 3: 3D GRAPHICS MODELS FOR PORES: a) Y1, b) X1, c) X2, d) X3 and e) X4

Table 10 shows the sum of the ratio of aggregate, *piaçava* fibers and EVA. It is possible to notice that samples X2 and X4 has cement matrix ratio lower than 50% and it does not happen for the other samples. When comparing tables 9 and 10, can be seen that when other elements different than cement are inserted in lightweight concrete, the porosity increases.

TABLE 10: SUM OF ALL ELEMENTS DIFFERENT THAN CEMENT AND PORES

Samples	Y1	X1	X2	X3	X4
Total (%)	38.10	40.57	50.17	44.12	53.11

4. CONCLUSION

X-ray microtomography technique proved to be able to identify inert elements like aggregates, EVA and *piaçava* fibers in concrete structure. The segmentation process allowed the characterization of these elements distribution, as well as the quantification of each element in the sample volume. The total porosity was also quantified and it can be concluded that the presence of more elements in lightweight concrete increases volume of pores in the samples.

ACKNOWLEDGEMENTS

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001. The authors also would like to thank to the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and Fundação de Amparo à Pesquisa do Estado do Rio de Janeiro (FAPERJ) for the financial support.

REFERENCES

[1] ASTM C125-18. *Standard Terminology Relating to Concrete and Concrete Aggregates*. ASTM International, West Conshohocken (2018).

[2] Chakradhara, Meesala, Bhattacharyya, Sriman and Barai, Sudhirkumar. "Influence of field recycled coarse aggregate on properties of concrete." Materials and Structures Vol. 44 No. 1 (2011): pp. 205-220. DOI https://doi.org/10.1617/s11527-010-9620-x.

[3] Mehta, Povindar and Monteiro, Paulo. *Concrete: Microstructure, Properties, and Materials*. McGraw-Hill Companies, California (2006).

[4] Neville, Adam M. *Properties of Concrete.* Pearson Education Limited, Edimburg (2011).

[5] Wang, Zhenshuang, Wang, Lijiu, Su, Haolin and Cui, Zhenglong. "Optimization of coarse aggregate content based on efficacy coefficient method." Journal of Wuhan University of Technology - Materials Science Edition Vol. 26 No. 2 (2011): pp. 329-334. DOI https://doi.org/10.1007/s11595-011-0224-2.

[6] Ćosić, K, Korat, Lidija, Ducman, Vilma and Netinger, Ivanka, "Influence of aggregate type and size on properties of pervious concrete." Construction and Building Materials Vol. 78 (2015): pp. 69-76. DOI https://doi.org/10.1016/j.conbuildmat.2014.12.073.