Three-Dimensional Image Processing Applied to the Characterization of Lightweight Mortar Reinforced with *Piassaba* Fibers

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Abstract Among the solutions to solve the environmental problems caused by the industrial development and the urbanization growing is to reuse industrial waste in civil construction. In this work are characterized mixtures of lightweight mortar using ethylene-vinyl acetate (EVA) grains and *piassaba* fibers as aggregates. The EVA is a residue from footwear industry, and the *piassaba* fibers act as reinforcement material in the mixture. We propose a methodology that uses micro-tomographic and three-dimensional image processing to identify and quantify the aggregates, pores, and micro-cracks produced by mechanical stress in the samples. Results for four types of mixtures were analyzed. The present technique offers appropriated results for these mixtures.

1 Introduction

The environmental protection today is a goal and a concern for all areas of knowledge. Solutions for the reuse of industrial waste are now mandatory and recycling this waste in civil construction is one of the possibilities. Among the alternatives has the use of Ethylene-vinyl acetate (also known as EVA) from the footwear industry in lightweight mortar, in nonstructural parts [1]. EVA is a residue that has low density, large capacity to deform, good thermal, and acoustic characteristics. It can be used to develop a class of material that allows associating the functions of sealing and thermal comfort with lightness. However, studies have shown a reduction of mechanical strength when the EVA is added to the mortar mixture if compared to conventional mixtures. To solve this problem, an alternative

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is using natural fibers in the mixture. In previous studies, it was shown that the addition of natural fibers improves the mechanical properties of the material. The fiber presence attenuates the stress propagation [2–4]. Among the natural fibers is the *piassaba* fiber from palm Attalea funifera Martius, broadly available in Southern Bahia, Brazil. In this work, lightweight concrete mixtures with EVA and *piassaba* fibers are analyzed.

To incorporate these new mixtures in civil construction, they should be featured in terms of their mechanical properties and internal structure. Generally the mechanical properties can be studied using mechanical tests as tensile and compressive tests. The internal structure can be characterized by nondestructive testing, such as ultrasound, microscopy, X-ray diffraction, and computed tomography. In this paper, we used micro-tomographic image processing techniques to study the internal structure of the material.

In previous works were made mechanical tests to characterize tensile stress and compression strength of this mixture (mortar + EVA + *piassaba*) [5]. Using two-dimensional image processing techniques, it was possible to identify the aggregates (there are EVA and *piassaba* fibers), pores, and micro-cracks in the study samples [6]. Still, the identification using two-dimensional images presents problems such as not considering the influence of fiber orientation. This work proposes the use of three-dimensional image processing to deepen the structural analysis of the lightweight mortar mixture reinforced with *piassaba* fibers improving the identification mechanism.

In the next section, the methodology used to study the lightweight mortar mixture is presented. In Sect. 3, are offered and discussed the results. The conclusions are shown in Sect. 4.

2 Methodology

In this work, four types of mixture were studied. The water/cement relation for all mixtures was 0.4, and the mass percentage of EVA and fibers for each type is shown in Table 1. These mixtures were used to prepare the samples. In these samples, the particle size distribution of EVA grains used varied from 850 to 1180 μm (16–20 mesh). The *piassaba* fibers were separated, cleaned, and cut with 10 mm length size. The sample preparation followed the Brazilian standard for fabrication and curing of cylindrical or prismatic concrete specimens (NBR 5738) [7].

Table 1 Characteristics of mixtures types

Mixture type	EVA (%)	Fiber (%)
(A) Pure mortar	0	0
(B) Mortar with EVA	1	0
(C) Mortar with EVA and fibers	1	1
(D) Mortar with fibers	0	1

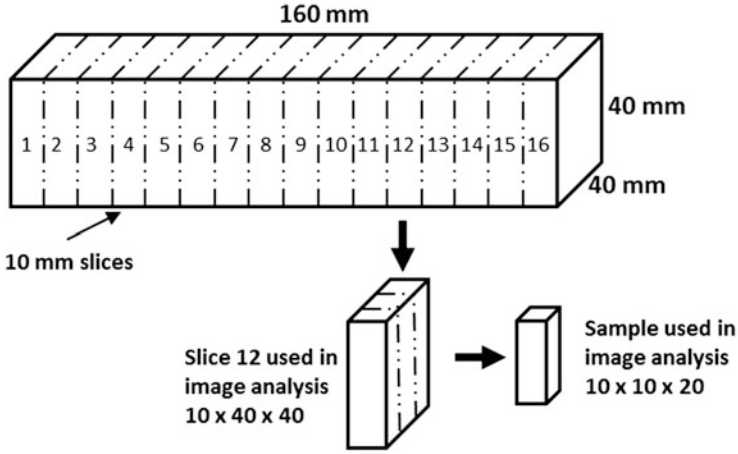

Fig. 1 Prismatic sample and scheme of cross-section slices of 10 mm for micro-tomographic image acquisition

Due to the limitations of the available micro-tomography equipment was necessary the extraction of smaller samples from the original specimen. The specimens were cut transversely into 16 slices with a length of 10 mm, as is shown in Fig. 1.

In previous works [6, 8], the mechanical properties of the mixtures were characterized using mechanical tests. After mechanical tests, the internal structure is composed of mortar, pores, EVA, *piassaba* fibers, and micro-cracks. These elements were characterized using two-dimensional image processing [5, 6].

In this work, the three-dimensional processing of the obtained micro-tomographic images was divided into two stages. The first, the preprocessing stage, includes the binarization of two-dimensional images, its rotation, the three-dimensional reconstruction, and the three-dimensional image cropping. The second is the three-dimensional image segmentation that includes the construction of a region's growth algorithm to make an accurate identification of the interest elements.

The binarization process transformed a grayscale image into a black and white image. As a result, the pixels in the image that represent mortar with cement paste and sand appear in black and those which represent the fibers, EVA grains, pores, and micro-cracks appear in white. These images are rotated to make easier the future crop. These two-dimensional images are stacked to frame the three-dimensional image.

As a result of the mechanical cut of the studied samples to fit in the tomography scanner, some edge problems in the image appeared. To solve these problems, edge techniques are applied in the three-dimensional object. This process was made using three criteria: external cropping, internal cropping, and external cropping with triangular edge. In the external cropping, the most external border point was detected, and this vertical/horizontal plane was selected for the cut. The same procedure, but with the more internal point in the border, was used in the internal cropping. In the external cropping with triangular edge, first we made an external cropping and, to avoid spurious pixels, the edges were cut using a triangular base prism. Of these criteria, the external cropping with triangular edge shows the best results.

After the obtaining the three-dimensional images, the region's growth algorithm is applied to identify the different elements. This algorithm uses an auxiliary matrix with the same size of original image to store the identified regions. During the process, the three-dimensional image is swept, using the neighborhood concepts. The regions that represent EVA, fibers, pores, and micro-cracks are identified in the auxiliary matrix. In addition, in the algorithm, for each region volumes, the number of voxels is computed. This value represents the volumes of each region.

3 Results and Discussion

The methodology described in the previous section was applied in samples of each mixture type. In samples of pure mortar, only pores are detected. In samples of mortar with EVA, there are pores and EVA grains. In mortar with EVA and *piassaba* fibers, we also find pores and EVA, but the fibers are identified in the mixture too. In mortar with *piassaba* fibers, we detect the pores and the fibers. In those samples submitted to mechanical tests, micro-cracks are also detected. This detection is possible by using volumetric parameters of identifying regions. It is possible to accurately recognize the presence of EVA, fibers, pores, and micro-cracks.

The steps of the methodology for a sample that contains mortar, fibers, and EVA are shown in Fig. 2. This figure is for a sample without mechanical test. Figure 2a represents the original two-dimensional micro-tomographic image. Figure 2b shows the same image after the binarization process. In Fig. 2b, the mortar is in black, and pores and the aggregates are in white. Figure 2c illustrates the result of the rotation process. Figure 2d presents the three-dimensional image, resultant of the stacking process from the two-dimensional slices. Note, in the image, the spurious pixels at the edges. Figure 2e shows the three-dimensional image after the cropping. Finally, Fig. 2f presents the image resulting from the identification process using region's growth algorithm. The identified regions are in different gray tones.

The problems presented in the two-dimensional analysis are solved. The EVA and fibers identified as pores in the two-dimensional analysis are correctly identified by this volumetrical analysis.

Using this methodology and the volumetric analysis, it was possible to identify correctly the EVA, fibers, and pores. Nevertheless, it is not possible to totally separate the micro-cracks from the pores when they have the same volume range. In this case another geometrical region parameter must be used.

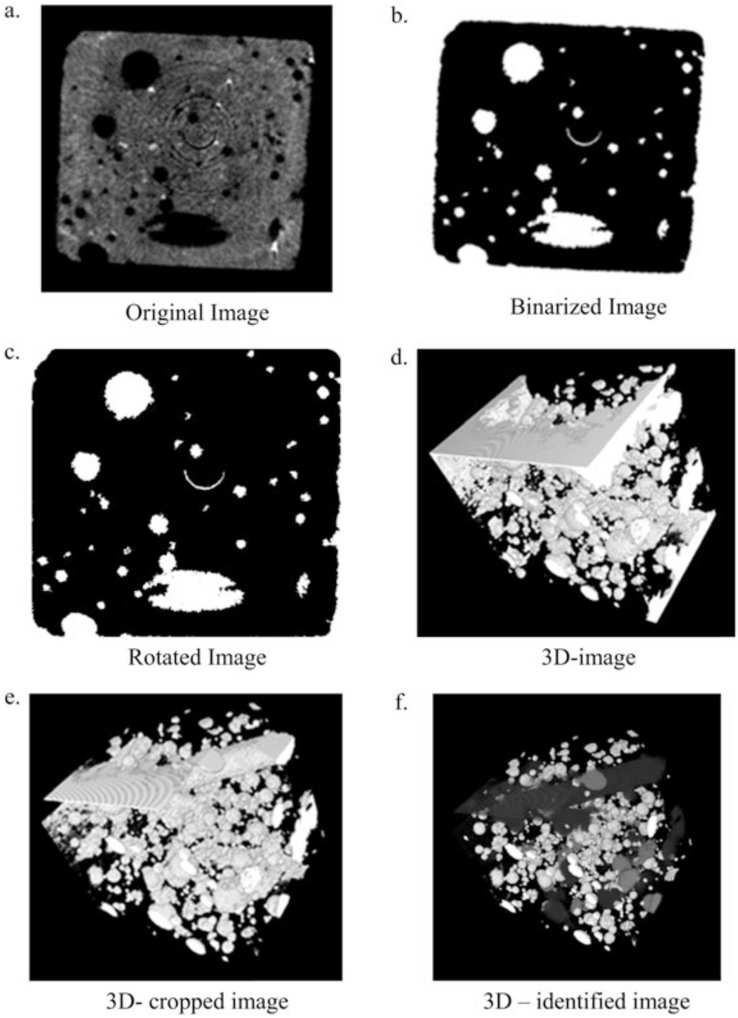

Fig. 2 Steps of the lightweight mortar mixture analysis methodology. In the figure, the sample contains mortar, fibers, and EVA

4 Conclusions

In this work, we obtained a methodology for microstructural analysis of samples of lightweight mortar with aggregates of EVA and *piassaba* fibers. This methodology is based on the three-dimensional image analysis. The images were obtained using micro-tomography and processed in two stages, the preprocessing stage that includes binarization, rotation, and the cropping process and the segmentation stage that uses a region growth algorithm.

As the methodology result, the aggregates, pores, and micro-cracks in the material were identified. Also it is possible to quantify the EVA, pores, and fibers. In samples submitted to mechanical tests, when the micro-cracks have volumes in the same range of the pores, the quantification failed. To solve this problem, other geometrical region parameters as the eccentricity must be considered.

The region's growth algorithm has a high computational cost hindering the processing of high volumes of three-dimensional objects. Computational alternatives, as parallel processing, must be developed in the future to solve this problem. In other research line, we propose the use of Fourier analysis to identify the different aggregates and micro-cracks and solve the edge problems.

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