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Application of X-ray microtomography to quality assessment of fibre cement boards

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HIGHLIGHTS

- The differences in material compactness of fibre-cement specimens were established.
- Using micro-CT specimens produce different images of their microstructure.
- The effect of microstructure tightening due to saturation was detectable.
- The described method can be applied as the useful tool for testing the structures.

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ABSTRACT

In this paper a method of X-ray microtomography (micro-CT) was employed for a direct insight into a microstructure of fibre cement boards of different quality. Four specimens were subjects of examination. Two parameters were determined to characterize the level of compaction of fibres in concrete matrix: mean-square displacement of migrating virtual particles after 500,000 of time steps and a diffusive tortuosity. The results of the investigation had revealed that fibre cement boards differing in density produce different images after processing with micro-CT method. The effect of microstructure tightening due to saturation using dying agent was also detectable.

1. Introduction

Increasing production volume of fibre cement boards and their application as high-quality building facade material enforces the engineers to improve the methods of quality testing of this building material [1]. A significant problem related to the fabrication of fibre cement boards is to prevent them from delamination during their forming. Several methods are in use to detect and assess the concentration and dimensions of defects after fabrication. Among them one applies a non-contact testing which applies the emitting and receiving the ultrasound Lamb waves to penetrate the volume of tested bulk material [2], what seems to be effective. However, there is a need to develop the procedures capable to visualize the defects shape and to determine their position within the board. The research of authors of this paper led to adopt the merits of the industrial X-ray microtomography (micro-CT) for the goal mentioned above. Fig. 1 presents schematic diagram of a typical lab-based measuring-system.

The micro-CT itself has been used to visualize the microstructure of concretes for some last decades [3–5]. The equipments for material testing with micro-CT technique are produced at present by a few firms and these apparatus are capable to perform tests on the small specimens of few millimeters size or on large elements of a few metres. They include the microfocal source of X-ray radiation, the movable table to place a specimen, and the flat panel with a radiation detector, which resolution usually equals 2000 × 2000 pixels. The structure of concrete is visualized on the cross-sections (tomograms) of the investigated specimen using grey scale convention related directly to the amount of local radiation absorption of the material. The grey scale covers dozens tens of grey levels and is ordered from white related to maximum of absorption to black related to the minimum, respectively. Unhy-

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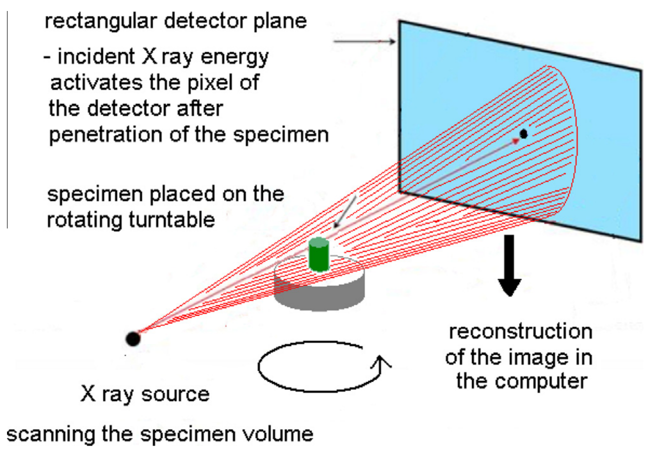

Fig. 1. Schematic diagram of a typical lab-based measuring-system.

drated cement particles and aggregate grains are objects of the greatest absorption. The hydratation products that cover major part of the cement matrix present slightly lower absorption ability. The next in the line are hydrated calcinates and at the end of the scale are the organic fibres (if present) and the regions of high porosity. The image resolution of microtomograms usually varies from 1 to 10 μm per voxel (volumetric 3D pixel). The advantage of micro-CT technique is a possibility of reconstruction of 3-dimensional image of investigated objects and to determine the volumetric part of the material occupied by bulk matrix, aggregates, voids, cracks, fibres, etc.

Some algorithms were developed for processing data representing the microstructure of objects tested using micro-CT technique. The method of 'marching cubes' was intended to draw complicated 3D surfaces using shading technique [6]. That is useful to recognize the shapes of the complex objects immersed in investigated volume. Another one, called 'random walk' was created to assess the magnitude of pore interconnectivity of tested material [7–10]. The latter algorithm performs the simulation of the diffusion of virtual particles, called 'walkers' in the interconnected network of pores. The walkers would migrate on neighbouring voxels obeying the information on voxels brightness (i.e. material density). The output of the random walk procedure is the walkers mean-square displacement $<r(t)^2>$ and on the basis of that the final microstructure qualifier, called 'diffusive tortuosity' is calculated. The method of generation of large amount of traverse lines crossing the air voids in random direction [10] was developed to determine the effective paste-void spacing what is related with the freeze-thaw durability of tested concrete. The authors of the paper have decided to apply the random walk procedure to assess the amount of the delaminations and low-density regions in fibre cement boards and therefore the way of applied image processing technique will be described in the further sections of the paper.

2. Survey of literature

Fibre-cement boards have been used in construction for over 100 years. They were invented by the Czech engineer Ludwik Hatschek. In 1900 he developed and patented the technology of producing damp-proof and nonflammable light-weight, strong and durable asbestos cement sheets, which he called "eternit" [2,11]. Because of the legal regulations, asbestos (deemed harmful) has been replaced with safe cellulose fibres [11]. Today's fibre-cement panels consist of 50–70% of cement while the other components include: mineral fibres (usually cellulose) and fillers (limestone powder, kaolin, etc). Besides being durable, they are characterized by high bending strength, moisture resistance and biological corrosion resistance [2,11].

The identification of delamination was the subject of research by, among others, Hertlein and Davis [12,13] recommended the state-of-the-art impulse response method for searching delamination in concrete floors. Ottosen et al. [14], Garbacz [15] and Sansalone [16] proposed to use the nondestructive impact-echo method for this purpose. They successfully applied the impact-echo method to small area floors. Hoła and Schabowicz et al. [17] came up with the idea of the combined use of the impulse response method and the impact-echo method. They showed this approach to be more effective in delamination testing, especially in the case of large area floors. Garbacz [15] and Sansalone [16] proposed to use the nondestructive impact-echo for this purpose. Also Berkowski, Schabowicz et al. [18] used this method. Kaszyński [19] and Stawiski [20] recommend using the ultrasonic method while according to Goszczyńska et al. [21], the acoustic emission method is the most suitable for this purpose. Schabowicz et al. [22,23] demonstrated for newly made foundation slabs that the combined methods of ultrasonic tomography and impact echo are highly effective in determining the depth of cracks.

The above survey of literature on the nondestructive testing of various material imperfections in board elements based on the cement matrix indicates that there is a need to a work on the testing of board elements with a small thickness, i.e. up to 15 mm. The most important fact is that all of the test was done in macro scale. In this paper authors proposed a method exploiting micro-CT technique in micro scale for the testing of cellulose fibre cement boards.

3. Description of investigated specimens

Four specimens were extracted from the different fibre cement boards of 8 mm of thickness delivered by the producer. Prior to the main research the boards were tested using the standard procedures to assess their performance. The material labelled 'A' was characterized by low absorbability n_w (6–8%) and relatively high bending strength of 25–30 MPa. The material labelled 'B' was made using the same technology as 'A', but its volume was additionally painted. The material labelled 'C' was characterized by higher absorbability n_w (10–15%) and lower bending strength of 10–15 MPa. Comparison of tested boards are presented in Table 1. The material labelled 'D' was made using the same technology as 'C' but its volume was also additionally coloured in structures. The amount of dye used to saturate the boards 'B' and 'D' was sufficient high to perform remarkable tightening of investigated structures. According to the requirements of the micro-CT scanning procedure cylindrical cores of 7 mm of diameter and 7 mm of height were cut off from the boards by drilling. Approximately 1 mm of outer surface was mechanically damaged and delaminated. The probe of maximal size which was possible to be reconstructed by using the Feldkamp algorithm (which is used in the Nanoscan device) in 1000 × 1000 × 1000 voxels resolution, was created in this way. Examination of microstructure compactness (pore interconnectivity) was performed on entire population of voxels. This allowed to register differences between 4 types microstructure compactness. The specimens were taken from random places, in such way that the results are representative for the entire plate. Plates had no defects and their quality was verified. It was assumed that the material was homogenous. The applied methods of water absorption and flexural strength testing have not given precise information about the microstructure of tested plates. For this purpose, the authors of publication decided to apply the method which allows testing of microstructure using X-ray. Results of the research indicate that the applied method shows