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Original Research Article

# Microstructural characterization of cellulose fibres in reinforced cement boards

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ABSTRACT

The microscopic analysis of the different cellulose fibre cement composites is presented. The observations of the fibres in optical microscope in transmitted light and in scanning electron microscope are described. The micro computed tomography (micro-CT) and SEM were used to determine the distribution of the fibres in the matrix. The investigated fibre cement boards were produced by extrusion process and panels were cured in natural conditions. The main goal of the research was application of different microscopic methods to analyze the fibres distribution as a result of a different methods of their production. Micro-CT was used for 3D visualization of fibres distribution in three different fibre cement boards. It was possible to determine the average diameter of the fibres and their concentration using the high-resolution mode of micro-CT scanning procedure. Finally, a procedure which can be applied as a useful tool for analysis of the different procedures used in production of fibre cement boards is described. This procedure can be successfully used in the quality control system of cellulose fibre distribution in cement composites.

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## 1. Introduction

The use of both metallic and non-metallic fibres to improve specific properties of mortar and concrete is not new. The behaviour of concrete reinforced with different kinds of fibres, which possess good tensile strength and bond properties have been studied in detail by several investigators, e.g. [1–3]. But in recent years there has been growing interest in utilizing natural fibres. Natural fibres, such as wood and cellulose fibres, are considered environmentally sustainable materials due to their renewability and biodegradability. The relatively high

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cost of industrial fibres makes the use of natural fibres as possible substitutes, additionally the ecological aspect is taken into consideration to produce eco-friendly construction materials.

The cellulose fibre cement boards belong to a special class of fibre-reinforced cementitious composites. They are widely used in building construction, as siding, ceilings, floors, roofs and tile backer boards. The cellulose fibre cement siding is commonly used as a replacement for wood siding, as it is less expensive and more durable, and has lower maintenance costs [4]. The fibre cement boards also referred to as precast fabrication, are becoming more and more important in the entire construction sector. Precast of concrete in a plant offers a variety of advantages, such as efficiency of construction processes, improved quality, better budget control, consumption of less materials and less waste on site. Precast concrete products provide the builder with quicker erection times, the reduced need for plant on site, easier management of construction sites and the realization from simple to complex structures [5–7].

The final properties of cellulose fibre cement composites depend, aside from the fibre and the matrix components, on the manufacturing process. The majority of the fabrication methods for cement composites reinforced with cellulose fibres in the pulp form are based on the Hatschek process, patented by L. Hatschek in 1900. It is a semi-continuous process comprised of three steps: sheet formation, board formation, and curing [5]. Other newer methods are extrusion of pulp cement mixtures and laminates with long fibres or sheet-like structures. Extrusion allows the alignment of the pulp fibres in the machine direction and the lamination methods allow reinforcement with semi-finished products, such as unidirectional long fibres, to ensure a higher level of enforcement in the desired direction [5]. The extrusion pulping is a technically and economically viable process for the chemo-mechanical pulping of non-wood fibres. Chemo-mechanical pulping provides a much higher yield (typically 80%) and a much lower use of chemicals. Moreover, extrusion pulping also allows cutting to a desired fibre length, so subsequently the pulps can be handled by bulk papermaking systems [8].

The mechanical properties, durability and microstructure of the autoclaved Hatschek-made cellulose fibre reinforced cements in the various environments are widely described in the literature. Akhavan et al. [4] presented a procedure to manufacture fibres cement boards in the laboratory, and alternative economical methods for increasing the boards' ductility. Ductility was measured using a 3-point or 4-point bending tests, and the microstructure of the boards was studied using scanning electron microscopy. Fernández-Carrasco et al. [9] tested the vegetable-fibre cement composites free of portlandite and with short curing process, and analyzed the influence of the curing conditions and the addition of pozzolanic material on the hydration of Portland cement–fibre matrices.

The final properties of cellulose fibre cement composites and durability primarily depends on its microstructure. The information concerned the microstructure of the cellulose fibre cement boards produced by extrusion pulping process are missing. Tonoli et al. [10] analyzed the effects of natural weathering on microstructure and mineral composition of cementitious roofing tiles reinforced with fique fibre. Savastano et al. [11] tested microstructure and mechanical properties of waste fibre – cement composites, but none of them concerns the extrusion process. Soroushian et al. [12] applied the extrusion procedure to prepare cellulose pulp cement composites with up to 8 wt% fibres. He analyzed the effect of fibre origin (recycled, softwood and hardwood pulps) and content (5, 10 and 15 wt%) on cement composites processed by extrusion.

Hola, Schabowicz, et al. [13,14] presented non-destructive and semi-destructive methods of the concrete structure diagnostic in relation to their durability. They focused on the methods and techniques that are useful for assessing the durability of concrete structures depending on the main degradation mechanism and its final effects on durability. Also authors in [15–17] used acoustic methods for non-destructive identification of delaminations in cement based elements. In paper [15] an original methodology for the non-destructive identification of delaminations in concrete floor toppings using both, the impulse-response and impact-echo acoustic methods was showed. Additionally, an example of the practical use of the analyzed methodology was presented. Several non-destructive methods were compared and applied to analyze the cracked foundation slab in [16]. Berkowski et al. [17] analyzed the cracks and mechanical durability of concrete from real structure using different non-destructive methods.

Goszczynska et al. [18] used acoustic emission method for experimental validation of concrete crack identification and location. Application of acoustic emission method to determine critical stress in fibre reinforced mortar beams was presented in [19]. All of mentioned above authors made their test for concrete elements using NDT methods, only Neithalath et al. [20] presented acoustic performance and damping behaviour of cellulose-cement composites.

At the same time the X-ray microtopography technique has been developed to study the microstructures of different materials, especially for non-destructive characterization of the internal structure of porous material [21]. Li-Ping Guo et al. [22] investigated the effects of mineral admixtures on initial defects existing in high-performance concrete microstructures using a high-resolution X-ray micro-CT. Cnudde et al. [23] were using micro-CT method to determine the impregnation depth of water repellents and consolidants inside natural building stones. 3D information about the total porosity and the pore size distribution was obtained with the combination of micro-CT and home-made 3D software [24]. Wang et al. [25] used this technique to produce the X-ray tomography images of porous metal fibre sintered sheet with 80% porosity.

In general the micro-CT has been used to visualize the microstructure of concrete for some last decades. The equipment for material testing with micro-CT technique are produced at present by a few companies and these apparatus are capable to perform tests on the small specimens of few millimetres 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 $2000 \times 2000$ pixels. The structure of concrete is visualized on the cross-sections (tomograms) of the investigated specimen

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