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The contribution of fiber reinforcement system to the overall toughness of cellulose fiber concrete panels

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HIGHLIGHTS

- The procedure of destruction of internal fiber network structure due to pyrolysis are presented.
- The analysis of AE signal shows that damages appears in later phase of the process.

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ABSTRACT

The paper concerns the role of cellulose reinforcements in overall mechanical toughness of fiber concrete panels applied as facade building material. The results of mechanical tests performed on specimens in as delivered state as well as on specimens which underwent the procedure of destruction of internal fiber network structure due to pyrolysis are presented. The results of mechanical tests let the authors to calculate the work of fracture for six different mechanical conditions. Moreover the analysis of registered Acoustic Emission (AE) signal had revealed that the investigated process of destruction begins with the brittle crack generation and growth while major damages of reinforcement system appears in later phase of the process.

1. Introduction

Fiber cement panels being frequent applied as building facade material are exposed to the different mechanical hazards. One can mention the following adverse factors: wind impacts, ice clods hits, thermal stresses etc. One of the measures enabling the evaluation the resistance of the panels to the failure is a mechanical toughness understood here as the integrated product of applied stress and strain per unit cross-section of investigated board. The fracture process developing in considered building material is complex in that the strains are not uniformly distributed during fracture, particularly in the regions of cracks. The facade panels are usually fixed to the wall construction on their edgings what makes them exposed to the flexural stresses. The currently applied fiber cement panels are designed in such a way to carry the mechanical load by the cellulose fiber reinforcement. If a certain fiber section is damaged therefore the carried stress in it necessarily drops to zero. When this occurs the load must be transferred to the brittle concrete matrix by shear stresses. The effectiveness of that transfer depends on the quality of the bonding between fibers and matrix and also on local concentration of fibers. The schematic diagram of stress distribution in the vicinity of single gap between two fibers is presented in Fig. 1. As the service performance of fiber cement panels may be affected by improper distribution of reinforcement (i.e. non uniform, low concentration or of poor fiber quality), several testing methods were proposed for testing the board performance. Among them one can mention Drelich, Gorzelanczyk, Pakula, Schabowicz who build automated control system of cellulose fiber cement panels with a non-contact ultrasound scanner emitting and receiving the ultrasonic Lamb waves [1]. Hertlein and Davis [2,3] recommended the impact-echo method also combined with impulse response method for searching delamination in concrete elements. Kaszyński [4] recommend using the ultrasonic method while according to Goszczyńska et al. [5], the acoustic emission method is the most suitable for this purpose. Ranachowski, Schabowicz et al. [6] used the X-ray microtomography to quality assessment of fiber cement panels. Van Vlack described shear stress increase caused by the gap between fibers in mechanically loaded fiber concrete composite [7]. Schabowicz et al. [8,9] came up with the idea of the combined use of the ultrasonic tomography, impulse response method and

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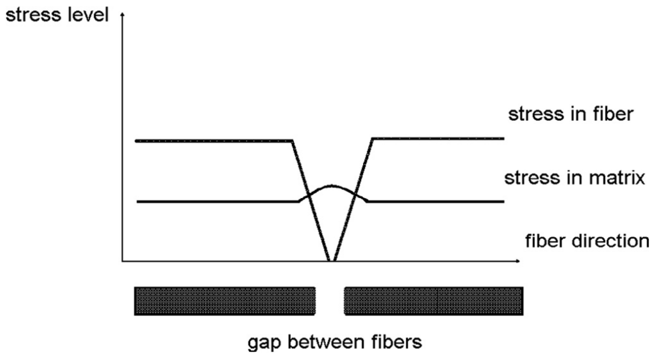

Fig. 1. Shear stress increase caused by the gap between fibers in mechanically loaded fiber concrete composite (after [7]).

the impact-echo method. They showed this approach to be more effective in different imperfection testing especially in determining the depth of cracks. Berkowski, Schabowicz et al. [10] proposed to use the nondestructive impact-echo for this purpose. Neithalath et al. [11] described acoustic performance and damping behavior of cellulose-cement composites. Also Ranachowski et al. [12] explained the determination of diffusive tortuosity in concrete specimens using X-ray microtomography.

The aim of this paper is to demonstrate the contribution of the fiber reinforced system to the entire value of mechanic toughness of investigated panels by presenting the results of mechano-acoustic loading tests.

2. Investigation of mechanic toughness of fiber concrete panels

2.1. Description of material and investigated specimens

Fiber-cement panels are well known in building area for over 100 years. Ludwik Hatschek, Czech engineer, invented them in 1900. He developed and patented the technology of producing damp-proof and nonflammable light-weight, strong and durable asbestos cement sheets, which has been nowadays replaced with safe cellulose fibers [13]. Now it is called this technology Hatschek process. Typical fiber-cement panels consist about 60% of cement, 4–10% of cellulose fibers and fillers. Hannant described the idea of using cellulose fiber in his book [14]. Some of the producers during the production of fiber cement panels use different technology and called that extrusion process. This process is well described in [15]. Hatschek process for fiber cement panels production is very popular in Europe and in the USA, but extrusion process is very popular in Asia, especially in Japan.

Three sets of specimens made of three different materials using extrusion process underwent the examination. Altogether eighteen specimens (3 × 6) were extracted from the different fiber cement panels of 10 mm of thickness delivered by the producer. Prior to the main research the panels were tested using the standard procedures [13] to assess their performance. The material labelled 'A' was characterized by absorbability n_w (8–10%) and bending strength of panels 11–13 MPa. Considering the data obtained from the producer, the concentration of fibers by weight in that material equaled 6% of good quality cellulose with length 2,5 mm. The material labelled 'B' was made using the same technology as 'A', but contained 6% of fibers by weight of recycled cellulose with length 1 mm and bending strength of panels 8,5–10 MPa. The material labelled 'C' was characterized by lower bending strength of 3–4 MPa and contained 4% of fibers by weight of good quality cellulose as a raw material with length 2,5 mm. Due to faulty technology the cellulose matrix was damaged. The spacing of fibers was non-uniform and several fiber agglomerates were present in the bulk material in the panels of type C what was possible to recognize by observing the fractured regions in that material. Tested specimens and comparison of tested panels are presented in Table 1.

Specimens A, B and C with index 1, 2 and 3 prepared of all investigated materials underwent the mechanical tests in the state as delivered. Specimens A, B and C with index 4, 5 and 6 were stored in an electric oven for 2 h at temperature of 230 °C. That treatment resulted in decomposition of cellulose fiber reinforcement due to process of pyrolysis. The authors have observed in their practise that the facade boards exposed directly to the sun in extremal conditions could have raised their temperature up to 70 centigrades. In these conditions degradation of performance of the organic cellulose fiber might be evoked. The best idea would be perform the investigation applying the real heating process and keep the specimens in increased temperature for appropriate period. However the authors decided to speed up the degradation due to Arrhenius law and demonstrate the results what can occur after several seasons of the exploitation of the fiber cellulose boards.

2.2. Procedure of mechanical loading

The specimens were loaded using in house designed machine for three point flexural tests. The samples had the following dimensions: width: 20 mm and length 100 mm. The span between supporting pins was 60 mm. Loading pin was powered by precision drive including silent stepper motor and was descending at a constant speed of 0.01 mm per second. Testing procedure cancelled within 100–300 s so it can be treated as quasi-static. Loading pin was acoustically coupled with a broadband Acoustic Emission sensor to record the signals evoked by material destruction processes. Additionally the testing machine was equipped with tensometric force gage to register the loading force with an uncertainty not exceeding of 1%. The current level of loading force dependent on sample deflection combined with Acoustic Emission signal was registered in a PC computer at a rate of 88.2 kilosamples per second using the fast acquisition card AD9118 (2 × 12 bit), made by ADLINK Technology Inc. The schematic diagram of a specimen loading method is shown in Fig. 2.

2.3. Calculation of mechanical toughness

Work of flexural test W_f was determined as the work made over the deflection curve, i.e. it equaled the integrated product of applied stress and strain per unit cross-section of investigated board. The fracture process was performed starting with initial force F_0 equaled 2 N and continued until final decrease to 50% of maximum load $F_{0.5MAX}$.

$$W_f = \frac{1}{S}\int_{F_0}^{F_{0.5MAX}} F\,da \tag{1}$$

here S denotes specimen cross section [m^2] and a- specimen deflection under the loading pin.

Since the loading force was in fact registered as a table of k digital readings $F_n\,(a)$ prepared by the acquisition system at a rate of one per second, the integral was replaced by the following sum:

$$W_f \approx \frac{1}{S}\sum_{n=1}^{n=k} F_n\,(a)\,\Delta a \tag{2}$$

here Δa denotes sample deflection under the loading pin executed over one measuring cycle, i.e. 0.01 s.