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Methods of testing the properties of fibre-cement composites

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Abstract. The paper deals with process of manufacturing the fibre-cement materials and methods of testing their climatic performance. Basic raw materials for production fibre-cement sheets are cement, cellulose fibers, reinforcing fibers - polyvinyl alcohol (PVA) fibers, filler, additives and water. Production follows the modified Hatschek's technology. The paper described the most important tests for climatic performance: Freeze-thaw test and Heat rain test. The fibre-cement profiled sheets were tested. The Freeze-thaw test includes assessment of frost resistance, precipitated salts efflorescence on the face-side surface, peeling of the coating on the edges, peeling of the coating on the face-side surface, longitudinal cracks in the various locations on the face-side, transverse cracks in the various locations on the face-side, shape deformation, swelling water between the layers of coating and material delamination on the edges. The frost resistance RL for fibre-cement profiled sheets after 100 freeze-thaw cycles was 0.95, when min. RL = 0.70. The fibre-cement profiled sheets were tested to 50 heat-rain cycles. After 50 cycles, the samples were checked for cracking (longitudinal, transverse and at the fixing points), delamination and other visible defects (especially the presence of formed drops on the underside of corrugated sheets). The tested modified recipe of fibre-cement profiled sheet met the Heat rain test requirements.

1. Introduction

Asbestos cement products have been produced in Bohemia and Moravia since 1910. Own patent for the production of this covering was filed by Ludwig Hatschek in 1901. Ludwik Hatschek himself called the products "Eternit", meaning "everlasting". The covering met with great success relatively quickly, because it was light and it was possible to use it even in harsh climates, where it was not possible to use burnt roofing. Asbestos was used to produce these sheets until the nineties. Asbestos fibers have been reported as harmful to health, therefore asbestos has been replaced by cellulose fibers, synthetic fibers and other additives. This has resulted in creation of an ecologically clean product. Since 1996 asbestos-cement technology has been being replaced by fibre-cement technology - no asbestos [1].

2. Composition of fibre-cement composites

Basic raw materials for production fibre-cement sheets are cement, cellulose, reinforcing fibers, filler, additives and water. Production follows the modified Hatschek's technology.

2.1. Cement

As the name suggests, the main raw material is cement. Choosing the kind of cement depends on the type of final product, on the curing process, on manufacturing facilities, and in some cases on water temperature. Availability and economical aspect both also play important roles in choosing the type of cement. Properties important when choosing type of cement:

- Development of hydration heat
- Beginning and the end of the cement hardening
- Particle size (Blaine)
- Final strength properties.

2.2. Cellulose fibers

Cellulose fibers are used as procedural fibers. These fibers absorb cement and other additives on the surface. For the production of fibre-cement sheets 2 types of cellulosic fibers are used. Bleached or unbleached pine fibers and sulphate fibers - high performance fibers. When fibre-cement sheets are manufactured, the distribution of cellulose fibers in water is important. This division is usually performed in the pulper during the pulping controlled time. Properties of the pulp fibers are molded in the disc mills. There the specific surface fibers and the technological parameters of the procedural fibers are improved. When modifying the properties of the pulp fibers, the fibers are larger, fibers are more flexible and fibers have larger external surface area of the fiber. External structure of fibers becomes broken and the fiber surface becomes hairy [1,2].

2.3. Polyvinyl alcohol fibers

Polyvinyl alcohol fibers (PVA) are used as reinforcing fibers. When using the PVA fibers in a concrete or cement composites several advantages over competing fibers of other materials can be observed. PVA fibers have high tensile strength, relatively high modulus of elasticity, good chemical compatibility with Portland cement, a good affinity with water and PVA fibers are without any health risks [3]. PVA fiber of a thickness of 0.014 mm with a tensile strength of 1600 MPa, modulus of elasticity 37 GPa and possible elongation of 7% are used for fibre-cement products. Growing concern about the dangers of asbestos inhalation brought the PVA fibers into the limelight as a substitute for asbestos fibers. Studies show that PVA fibers represent less risk than chrysotile fibers because they are too big to breathe in. PVA fibers do not cause any tissue reactions [4].

2.4. Fillers

The most commonly used fillers in the production of fibre-cement sheets are micro silica (specific surface area of 15000 - 35000 m^2/kg), ground limestone (specific surface area 300-400 m^2/kg) or another suitable micronized filler. [1] Besides applications of microparticles are tested nanoparticles with the use of in cement composites with cellulose fibers to influence the properties of the cement composites [5]. The chart below shows the proportional representation of the various components of fibre-cement composites.

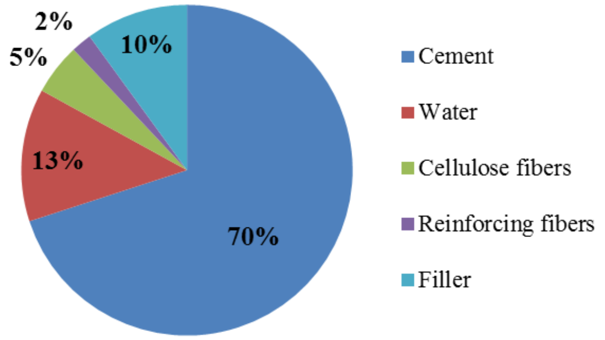


Figure 1. The proportional representation of the various components of fibre-cement composites.

3. Technology of production fibre-cement composites

The modified Hatschek's technology is used for the production of fibre-cement sheets. Hatschek machine for the production of fibre-cement was first developed in 1890 and it was logged on at the patent office by Ludwig Hatschek. The machine has been used in the same basic form till today, though modern Hatschek machines are much more productive, than the models at the start of the production. Hatschek process is particularly suitable for making flat and profiled sheets. This process is the process of filtering based on the drainage of the suspension of diluted through the cylindrical sieve. Thus, the primary layer consisting of fibers, cement, additives and fillers is separated on the sieve, and this layer is transferred to the endless filter carpet [6].

The fibrous component is mixed with cement and other additives in a turbomixer. From there it goes into the homogenizer where it regulates the density of the slurry. The suspension is transported into the production machine vats. In the vats, there are rotating sieves cylinders that transfer the fiber cement on a continuous layer. It is very important to maintain the constant and right level of suspension in the vat. If the level of the slurry moves, it could affect the thickness of each layer, and thus the final product. The Hatschek production machine has normally 3 or 4 manufacturing vats and contribution of each vat is about 0.3 mm. The individual layers are piled on the format roller, until the desired thickness of the product is reached.

The size of the holes on the sieve reaches values around 0.4 mm (400 microns) and a non-fibrous component used in the production are much smaller than the hole of the sieve, and that could cause their passage. Capturing the non-fibrous material therefore depends on the formation of the filtration layer of fibers on the surface of the sieve. Filter layer of fibers is created on the surface of the sieve at a short distance from the immersion of sieve, which is immersed into the suspension. Formation of the film continues on the sieve, but now it contains a lower proportion of the fibers and a higher proportion of non-fibrous materials. Subsequently, the film is dewatered and it is removed from the sieve by plotting on a continuous belt. Main drainage is performed by means of vacuum chambers, which are disposed on the upper side of the strip between the last production vat and a format cylinder. A vacuum chamber with a large amount of water is used to clean the belt.

The fibre-cement layer is transferred on the continuous belt and the belt is transferred on a format roller. After winding the desired thickness the material is cut and moves on the tow table. Winding the desired thickness of material on the format roller varies by product range in the range of 5-7 mm.
Fibre-cement material is cut to desired dimensions by steel disks, or there is cutting shapes, including holes and edges on the cutting press. All the parings, which represent approximately 10-20 % of total production, go to the dissolver and are reused in the production. The cutting material is transferred to the corrugator head, where it is formed to the corrugated roofing.

The individual sheets are located on the steel templates which are placed on carriages. The carriages are transported to pre-heating tunnel where they are hydrated over a period of 8-10 hours at about 60 °C. The steel templates are partly heated to prevent the flow of heat from the sheets during cure and achieve the required handling strength. Then the individual sheets are separated from the steel template and are stacked on wooden pallets. Each template is then brushed and sprayed with a thin layer of mineral oil in the oil machine. Application of oil ensures good separation of the steel plates and fibre-cement sheets after curing. After 10 hours, the sheets are moved on the wooden pallets and the pallets are transported into the ripening warehouse where the sheets under controlled conditions obtain final properties. Time for storing plates in the ripening warehouse is at least 7 days [1].

4. Methods for testing the properties of fibre-cement composites

Fibre-cement is an ideal building material for protecting the external shell of the building and it is used for roofing and facade cladding on new buildings and renovations. Today's fibre-cement covering is already incomparable with the one that was produced 30 to 40 years ago, the environmentally neutral raw material such as cement, water, ground limestone, microsilica, cellulose and synthetic fibers are used to produce fibre-cement roofing materials. Combining these materials makes it possible to form a non-combustible building material which is suitable for any type of building. Fibre-cement material combines the technical properties such as strength, durability, and weather resistance, easy workability, efficiency and environmental safety. It is resistant to water, frost, rot, corrosion, and can be processed by conventional tools on the construction site [1].

The following text expresses the most important tests (Freeze-thaw test and Heat rain test) for climatic performance. During a proposal of new or modified recipe must be verified the impact of changes in the recipe on the final properties of fibre-cement sheets.

4.1. Freeze-thaw test (EN 494+A1 Fibre-cement profiled sheets and fittings - Product specification and test methods)

The specimens were longitudinally cut from the middle of a complete sheet, with two complete corrugations. Twenty specimens were tested. Specimens were transversely cut to a length allowing a span of 12 times the height of corrugation.

The specimens were divided at random into two lots of 10. The first lot of 10 specimens was tested on the breaking load test (or to the bending moment test for short sheets). At the same time, the second lot of specimens was immersed in water at ambient temperature (> 5 °C) for 48 hours. Then the second lot of specimens was subjected to 100 freeze-thaw cycles:

- cooling (freeze) in the freezer which reach a temperature of (-20 ± 4) °C within 1 hour to 2 hour and holding this temperature for a further 1 hour
- heating (thawing) in the water bath which reach a temperature of (20 ± 4) °C within 1 hour to 2 hour and holding at this temperature for a further 1hour.

Then the breaking load test (or to the bending moment test for short sheets) was done. The following figure 2 and figure 3 show the results of freeze-thaw test of the fibre-cement profiled sheets.

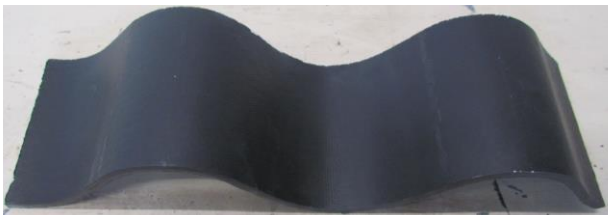


Figure 2. Sample of fibre-cement profiled sheet before freeze-thaw test.

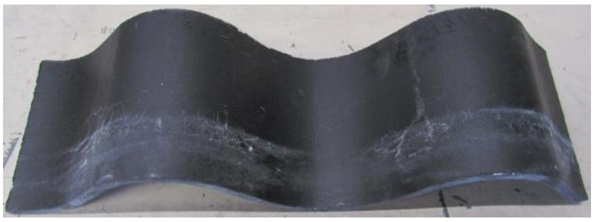


Figure 3. Sample of fibre-cement profiled sheet after 100 cycles of freeze-thaw.

For each of the two lots, the mean breaking load or bending moment and the standard deviation at the value was calculate. From these values is subsequently determined R_L ratio (see equation (1) – (3)). The ration R_L shall be not less than 0.70 after 100 freeze-thaw cycles [7]:

$$L_2 = X_2 - (0{,}58 \times s_2) \tag{1}$$

Which is the lower estimation of the mean breaking load or bending moment after freeze-thaw cycles at 95 % confidence level (second lot):

$$L_1 = X_1 + (0{,}58 \times s_1) \tag{2}$$

Which is the upper estimation of the mean breaking load or bending moment at 95 % confidence level of the reference lot (first lot):

$$R_L = \frac{L_2}{L_1} \tag{3}$$

The R_L ratio for fibre-cement profiled sheets (Cembrit, type A5, A6.5, A6, B7, B8) is min. 0.70 after 100 freeze-thaw cycles [1]. To evaluate the test for frost resistance is not only R_L ratio but also the assessment of following properties: Precipitated salts efflorescence on the face-side surface, peeling of the coating – on the edges, peeling of the coating – on the face-side surface, longitudinal cracks – in the various locations on the face-side, transverse cracks – in the various locations on the face-side, shape deformation, swelling - water between the layers of coating and material, delamination - on the edges [7]. The results of freeze-thaw test are of modified recipe shown in the table 1.

Table 1. The results of the freeze-thaw test of modified recipe.

	Reference	100 freeze-thaw cycles
Δ breaking load (kN/m)	4.77	4.74
L_1	4.82	-
L_2	-	4.62
R_L ratio		0.95

Together with the assessment of frost resistance (R_L) on the samples the peeling of paint on edges was assessed as it shown on the figure 2 and figure 3. In this test, there shall be no cracks on the paint leading to subsequent peeling of the surface treatment. The occurrence of efflorescence on the sample after 100 cycles is not a major problem because the main objective is to verify the durability of the surface treatment.

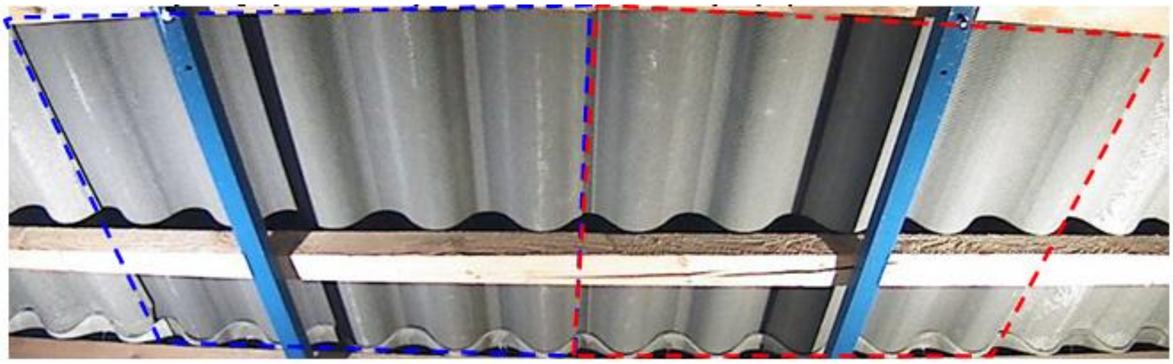
4.2. Heat rain (according to EN 494+A1 Fibre-cement profiled sheets and fittings - Product specification and test methods)

The specimens shall comprise a minimum of one full sized sheet with the underlapping and overlapping sheets/strips surrounding it a minimum of ½ sized sheets. 12 specimens for sheets of length equal to or less than 0.9 m or 9 specimens for longer sheets were tested. The specimens were stored for 7 days in a laboratory atmosphere. Each sheet were laid with overlaps at the four edges. The specimens were fixed on the frame according to regulations or, if no regulations exist, to manufacturer's instructions. One installation system, which the manufacturer regards as decisive for the sheets, shall be selected. The upper face of the sheets was tested to 50 cycles without interruption in accordance with table 2. Any visible cracks, delamination or other defects in the fibre-cement sheets shall not be of such degree as to affect their performance in use after 50 heat-rain cycles [7].

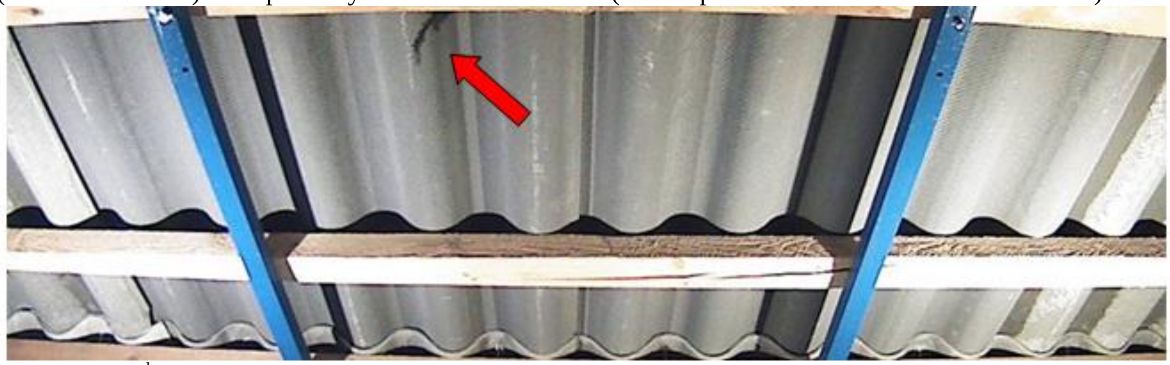
Table 2. Heat-rain cycle

Cycles	Duration
Wetting 2.5 l/(m^2.min)	2 h 50 min
Pause	10 min
Heating (70 ± 5^{0}C)	2 h 50 min
Pause	10 min
Total cycle	6 h

The figure 4 shows the comparison of results of heat-rain test of the fibre-cement profiled sheets after 4 cycles. On the left in blue border is modified recipe and on the right in red border is standard recipe. On the sample with modified recipe we can see the longitudinal and transverse microcracks, resulting in faster moisture penetration. From the figure 4 there is a clear difference in the rate of development of moisture traces. Therefore, it is important to assess not only the final results but also continuous results of individual samples. The presence of wet traces on samples is not a reason for non-compliance, but in no case shouldn't be formed drops on the underside of corrugated sheets. After 50 cycles, the samples are checked for cracking (longitudinal, transverse and at the fixing points), delamination and other visible defects [1].



During the 1st cycle: 75 minutes of sprinkling seq. – First occurrence of moisture traces on the left sample (thickness 6.5 mm) most probably due to the loose screw (still no problem of the fibre-cement material)



During the 2nd cycle: First occurrence of water soaked through material on the left sample (longitudinal cracks), big spot is commented in the previous picture

During the 4th cycle: First occurrence of transverse cracks on the left sample (with combination of longitudinal cracks also)

Figure 4. The comparison of the results of standard (left blue border) and modified (right red border) recipes after 4 cycles.

5. Conclusion

Fibre-cement products must meet the high durability, aesthetic and utility requirements. To fulfill all these requirements, it is necessary to use in the production of fibre-cement sheets suitable materials, which must meet the strict quality requirements. Fibre-cement products are made exclusively from natural materials environmentally friendly. Using purely natural materials, the products are fully recyclable (e.g. use in comminuted state as an admixture in concrete, or use as permanent formwork), and in line with the trend of sustainable development. From the viewpoint of achieving the right durability of these products is a key parameter the right technological process of production. The perfect manufacturing technology is important for strength and durability of fibre-cement sheets when thin layers of fibre-cement are wrapping themselves and before final maturation are exposed under intense pressure in the press. Great-value is the testing the properties of the fiber-cement sheet. We can assume the durability of these materials from the results of water absorption tests, freeze-thaw test and heat-rain tests. The combination of tests allows us to deduce further features such as resistance to rain and resistance to flowing fluids. To achieve the high and stable quality of fiber cement products, the technological process of production must be carefully observed. The quality of fiber cementitious material can be influenced by both the variability of feedstocks and the changes in cure and aging. Consistent control of key stages of production contributes to non-problem production process and quality of produced sheets.

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