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TESTING THE PROPERTIES OF CEMENT AND GYPSUM BOARDS REINFORCED WITH NONWOVEN FABRICS MADE OF WASTE AND RECYCLED FIBRES

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Abstract

The article attempts to assess the possibility of using non-woven fabrics made of waste fibers in cladding panels. For this purpose, woolen and polypropylene nonwovens were tested for mass per unit area, characteristic opening size, and lengthwise and crosswise elongation at maximum strength. Non-woven fabrics were placed in the middle of the thickness of cement and gypsum boards and subjected to tests of density, thermal conductivity coefficient λ, and bending strength. The influence of individual nonwoven fabrics with different properties on the properties of the finished composite was determined. It was found that wool nonwoven fabrics had the best effect on the thermal conductivity coefficient. A better affinity for nonwoven fabrics was shown by gypsum mortar. The best influence on the bending strength of the panels had polyester non-woven fabrics with the lowest mass per unit area and the largest characteristic opening size.

Keywords:

Nonwoven fabrics;
Cement and gypsum boards;
Reinforced boards;
Bending strength;
Thermal conductivity coefficient.

1 Introduction

The global crisis causing increases in the prices of raw materials and the sustainable development policy led to the search for solutions aimed at the management of waste materials in the construction industry. One such solution aimed at improving the deformability of cement and gypsum products was the use of waste fibers as dispersed reinforcement in terms of their use in the production of cladding panels [1]. In recent years, similar attempts have been made to use waste fibers, e.g. wool and polyester fibers to create materials for acoustic and thermal insulation [2, 3].

When creating the boards, important problem was ensuring proper cooperation of the raw, untreated fibers with the cement and gypsum matrix. Particularly favorable results were obtained in the case of tanning sheep's wool. The introduction of fibers into cement boards improves thermal insulation properties, reduces the weight of the element, reduces the risk of cracking, and improves the acoustic insulation of the partition [4, 5]. It is expected that similar properties should be exhibited by needle-punched nonwoven due to the consolidation of loosely bound fibers. There are many types of needle-punched nonwoven made of recycled materials available on the market. This publication presents the results of research on the use of needled non-woven fabrics for reinforcing cement and gypsum boards. The results of tests of the nonwoven fabrics were presented and the effect of additives on the density of the composite, its thermal insulation properties, and bending strength was analyzed. In addition, microscopic photos were taken to assess the cooperation of the non-woven fabric with the matrix.

2 Research methodology

Nonwoven fabrics with different physical properties were selected for the tests. At the beginning, tests of mass per unit area, characteristic opening size, and tensile elongation were made. The tests were carried out in accordance with the applicable harmonized standards for geosynthetics in the laboratory of textile materials of the Akademia Techniczno-Humanistyczna in Bielsko-Biała. Mass per unit area was determined according to EN ISO 9864:2007 standard [6]. For this purpose, 10 samples of 10 x 10 cm were prepared from each type of nonwoven fabric. The Mass per unit area of each of them was determined with an accuracy of 0.5 % and then weighed with an accuracy of 0.1 %. The mass per unit area of the samples was determined from the formula (1)

$$M_a = \frac{m_s}{A} \ \left[\frac{g}{m^2}\right], \qquad (1)$$

where m_s – mass of the sample [g], A – sample area [m^2].

The characteristic opening size test was performed according to EN ISO 12956:2020-6 standard [7]. For each type of nonwoven fabric, 5 round samples with a diameter of 20 cm each were made. Test samples were immersed in water containing a wetting agent (sodium alkylarylsulfonate) and allowed to saturate for 12 hours. The sample was then removed from the water and placed in the sieving apparatus. The granular material was evenly distributed over the sample, the water supply was opened, which evenly sprayed the entire surface of the sample, and the screening device was turned on. The particulate material was sieved for 10 minutes. Then, the sieved granular material and the test sample with the granular material retained thereon were dried separately, and the dry mass of the retained granular material was determined. The Graining curve was determined from the dried material that passed through the tested sample. On the basis of this curve, the characteristic opening size O90 was determined, corresponding to the largest grain size of the screened material, which together with smaller ones constitute 90 % of the material that passed through the tested sample.

Elongation at maximum strength was determined according to EN ISO 10319:2015-08 standard [8]. Five samples of each nonwoven fabric with dimensions of 20 cm x 20 cm were used to test the elongation in the longitudinal direction and in the transverse direction. The samples were sequentially fixed in the testing machine, the machine was started with a constant speed and the test was continued until the samples broke. The maximum elongation values were read from the results obtained using the computer software of the testing machine.

On the basis of preliminary tests, the pattern of the nonwoven fabric, the method, and the frequency of needling, which had a positive effect on the properties of the board, were determined. Nonwoven fabrics with the highest surface weight were rejected because they were characterized by low porosity, which translated into poorer affinity to the matrix.

The influence of the placed non-woven fabric on the density of the sample, the thermal conductivity coefficient λ, and the three-point bending strength of cement and gypsum mortars was investigated. The tests were carried out in the Building Materials Laboratory of Akademia Techniczno-Humanistyczna in Bielsko-Biała and in the Research and Development Laboratory of SEMPRE Farby in Bielsko-Biała. The measurement of the thermal conductivity coefficient was performed on a 300 x 300 x 12 mm sample with the use of an apparatus for measuring the λ coefficient – a lambda meter. The sample is placed in the device chamber between the upper and lower plates, which maintain temperatures of 0 °C and 20 °C. After stabilizing the temperature of the sample and the heat flux, the heat flux density flowing through the tested material is measured. On this basis, the device determines the value of the thermal conductivity coefficient λ.

The bending strength test was carried out on samples with dimensions of 12 x 75 x 150 mm using a testing machine. The samples were bent at a constant speed in the three-point bending scheme, and the spacing of the supports was 10 cm, in accordance with the procedure contained in the standard EN 196-1:2016-07 standard [9]. The thickness of the samples on which the tests were carried out, amounting to 12 mm, was related to the potential thickness of the non-woven cement boards.

Microscopic photos of the samples were taken on composite cross-sections using the JEOL JSM-5500 LV scanning electron microscope at various magnifications: x50, x300, and x1000.

3 Samples preparation

On the basis of research [1] on the reinforcement of analogous boards with waste and recycled fibers, two types of fibers with high availability and a beneficial effect on the bending strength of the samples were selected – polyester and wool fibers. Their short characteristics are presented in Table 1.

Table 1: List of fibers used to make non-woven fabrics for reinforcing cement and gypsum boards.

No.	Fiber type	Fiber origin	Fibres description	Thickness
P1 P2 P3	polyester fibres	the raw material for the production of fibers is made in the recycling process of PES waste	fibers of different thickness, length declared by the manufacturer: 64 mm	24 - 29 μm
W1 W2	tanning wool fibres	waste resulting from the shearing of dressed sheepskins	off-spec fibers of different thickness and length	163 pprox.. 25 μm

From these fibers, using a textile line with a needle-punching machine, nonwovens were made, differing in the number of needle-punching, which directly translated into the thickness of the nonwovens obtained in this way [10].

On the basis of research [1] and preliminary studies, the composition of the dry mix with optimal rheological properties for creating boards was determined. Portland cement CEM I 42.5 R Górażdże and sand with a grain size of 0.0-0.5 mm from the KOTLARNIA S.A. sand mine were used. The size distribution of sand grains is shown in Fig. 1.

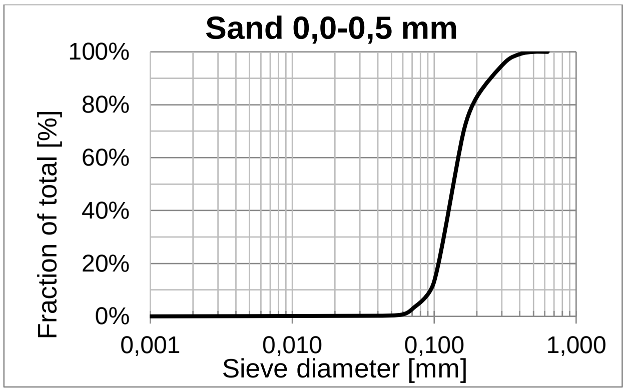

Fig. 1: Particle size distribution of aggregates.

In addition, in order to improve the working consistency of the cement mortar and reduce the amount of water used to improve the bending strength, it was decided to use the superplasticizer Melment F10 – polycondensate of sulfonated melamine and formaldehyde. In addition, due to the desire to remove free air voids that deteriorate the strength and homogeneity of the sample, a defoamer – Vinnapor was used. The optimal mortar consistency determined on the flow table was determined experimentally in accordance with the EN 1015-3:2000 standard [11]. It was similar for cement and gypsum mortar and it was about 220 ÷ 240 mm – with such consistency, the mortar did not delaminate and showed proper cooperation with the nonwoven fabric – it penetrated well through the pores of the non-woven fabric, connecting with it. The amount of superplasticizer added depended on the fulfillment of the imposed consistency criterion. The effect of the superplasticizer and defoamer addition on the microstructure of the cement matrix is shown in Fig. 2.

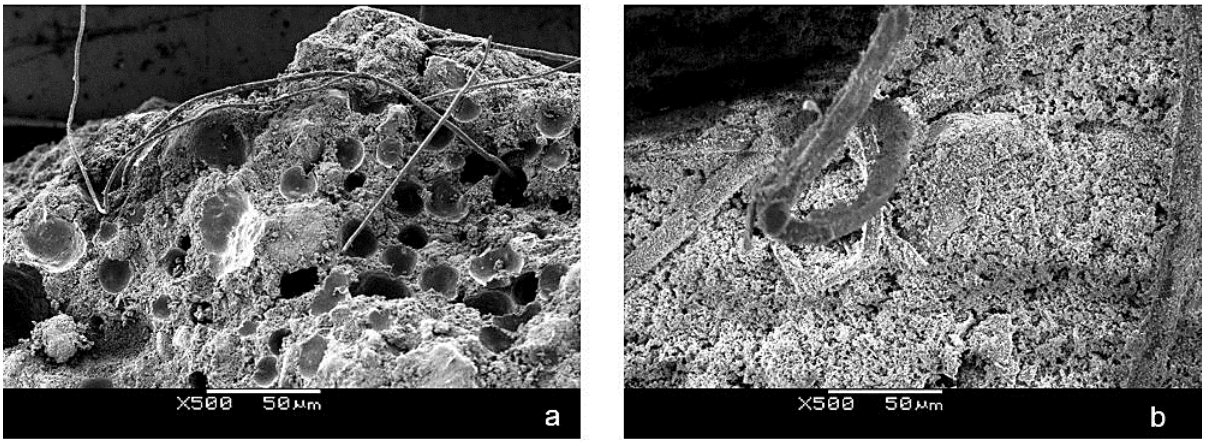

Fig. 2: Microstructure of the cement matrix before: a) and after b) addition of superplasticizer and defoamer.

Table 2 shows the composition of the recipe for the cement part of cement-non-woven boards.

Table 2: Composition of the cement part of the samples.

Raw material	Mass per 1 kg of dry mortar [g]
Cement CEM I 42,5 R	400
Sand 0.0-0.5 mm	597.4
Superplasticizer	2.0
Defoamer	0.6
water	160

Preliminary tests allowed us to select the optimal gypsum for this type of application. Due to the longer setting time than the other tested gypsums and good flow after adding a superplasticizer, it was decided to use Nowy Ląd GC-4I ceramic gypsum with a content of dehydrated calcium sulphate >90 %. As in the case of cement boards, the same superplasticizer was used. Table 3 shows the composition of the recipe for the gypsum part of gypsum-non-woven boards.

Table 3: Composition of the gypsum part of the samples.

Raw material	Mass per 1 kg of dry mix [g]
Ceramic gypsum Nowy Ląd GC-4I	995
Superplasticizer	5.0
Water	600

Immediately after mixing the cement and gypsum parts, half of the mortar was filled in the previously prepared form, which was leveled, then the non-woven fabric was laid out in such a way that it was finally in the middle of the thickness of the board. Then, the rest of the mortar was poured and the surface was leveled by gently sticking the non-woven fabric into the mortar. The whole was compacted by vibrating using a vibrating table.

4 Test results and discussion

The seasoning period of the samples before the strength test was 14 days. This was due to the planned use of the panels in the construction industry and related to the production conditions. After the standard time of 28 days [9], the differences between the strengths of individual samples leveled out, but in practice, the period of seasoning the material for such a long period in the plant would often be impossible. Samples for testing the thermal conductivity coefficient λ were also seasoned for 14 days. After this time, the sample was dried to a constant weight with a mass moisture content not exceeding 1 %. After reaching this level of humidity, the λ coefficient was measured. For each sample, 5 measurements of density, thermal conductivity, and bending strength were made. The averaged results of these tests are summarized in Table 4. The table also presents the results of tests on the properties of nonwovens: mass per unit area determined according to the EN ISO 9864:2007 standard

[6], characteristic opening size according to EN ISO 12956:2020-6 [7], and longitudinal and transverse elongation at maximum strength according to EN ISO 10319:2015-08 [8].

Table 4: Summary of test results.

No	Fiber type	Nonwoven fabric				Cement board with nonwoven			Gypsum board with nonwoven		
		Mass per unit area [6] [g/m^2]	Charakteristic opening size [7] [μm]	Elongation at maximum strength [8] [%]		Density 14 days [kg/m^2]	Bending strength 14 days [9] [MPa]	Thermal conductivity coefficient λ [W/(m·K)]	Density 14 days [kg/m^2]	Bending strength 14 days [9] [Mpa]	Thermal conductivity coefficient λ [W/(m·K)]
				longitudinal	transverse						
0	-	-	-	-	-	1730	4,02	0,4711	1248	4,12	0,3172
P1	polyester	150	160 ± 16	120	130	1670	4,76	0,3026	1211	5,81	0,2832
P2		300	90 ± 9	115	120	1642	4,53	0,2765	1198	4,96	0,2134
P3		500	85 ± 9	90	100	1609	4,16	0,2610	1168	3,82	0,1943
W1	tanning wool	280	120 ± 15	85	64	1618	3,21	0,2891	1202	5,42	0,2765
W2		550	75 ± 12	35	30	1327	1,28	0,1746	1063	1,68	0,1764

The results listed in Table 4 clearly indicate that polyester nonwovens exhibit greater elongation at maximum load than wool nonwovens. The reference samples without non-woven fabric were characterized by the highest density. The decrease in the board density was mainly due to the surface weight of the non-woven fabrics used – the increase in the mass per unit area reduced the weight of the board. This was mainly due to the fact that nonwoven fabrics with a higher mass per unit area were characterized by greater thickness, which meant that they occupied a larger volume in a sample with a constant thickness.

A similar relationship should be noted in the case of the thermal conductivity coefficient λ – the increase in the mass per unit area of the nonwoven fabric resulted in the improvement of thermal insulation properties. As in the case of the effect on the density, the greater mass per unit area of the non-woven fabric was associated with an increase in its share in the panel volume. Lower, and therefore more favorable, values of the thermal conductivity coefficient both in gypsum and cement boards were obtained in the case of boards reinforced with non-woven fabric made of wool.

The results presented in Table 4 indicate that non-woven fabrics made of polyester fibers had a clearly beneficial effect on improving the bending strength of cement boards. Except for the sample with the highest area weight P3 nonwoven, all polyester nonwovens also improved the flexural strength of the gypsum boards. In the example of the analyzed samples, it can be seen that the samples with a lower mass per unit area of the non-woven fabric were characterized by better bending strength. It was observed that the size of the pores in the nonwovens decreased with the increase in the mass per unit area. High porosity resulted in better affinity to the cement matrix and gypsum matrix, because it resulted in better permeation of the mortar between the fibers and better anchoring in the depth of the non-woven fabric. Wool nonwoven W2 with the highest mass per unit area 550 g/m^2 showed the lowest porosity and the greatest thickness so that both cement and gypsum were unable to penetrate the nonwoven, which is shown in the microscopic photos in Fig. 3.

Fig. 3: Microphotographs of W2 wool nonwoven with a mass per unit area of 550 g/m^2 in a cement matrix.

In Fig. 3a showing a cross-section of a cement board reinforced with a wool nonwoven fabric W2, numerous fibers protruding from the mortar can be seen. With greater approximations, one can observe the places where the fibers are embedded in the matrix and the free spaces between the fibers and the cement. Fig. 3c also shows mortar agglomerate trapped between the fibres. The lack of permeation of the thick woolen nonwoven resulted in the non-bonding of the parts above and below the nonwoven thus produced. This resulted in a complete lack of cooperation between these parts and their independent operation under the influence of the bending force. In such a situation, the sample cannot be treated as reinforced. This translated into definitely the worst results of flexural strength of samples with this non-woven fabric in both gypsum and cement matrix. These results were less than half the strength of the reference samples, which proves that the plates formed above and below the non-woven fabric function independently. In the case of the polyester non-woven fabric with the highest mass per unit area placed in the gypsum matrix, a decrease in the bending strength of the element was also noted compared to the reference sample.

A general trend was found to decrease the flexural strength with increasing mass per unit area of the nonwoven fabrics, and a better affinity of the nonwoven fabrics to the gypsum matrix than to the cement matrix. The best reinforcement effect of the sample was noted in the case of the P1 non-woven fabric made of polyester fibers with the lowest mass per unit area 150 g/m^2 placed in a gypsum matrix – the bending strength of the sample was approx. 40 % higher than in the case of the unreinforced reference sample. Microscopic photos of this sample confirm the good cooperation of the matrix with the non-woven fabric – the non-woven fabric is well covered with mortar, and every visible fiber is embedded in the matrix, Fig. 4.

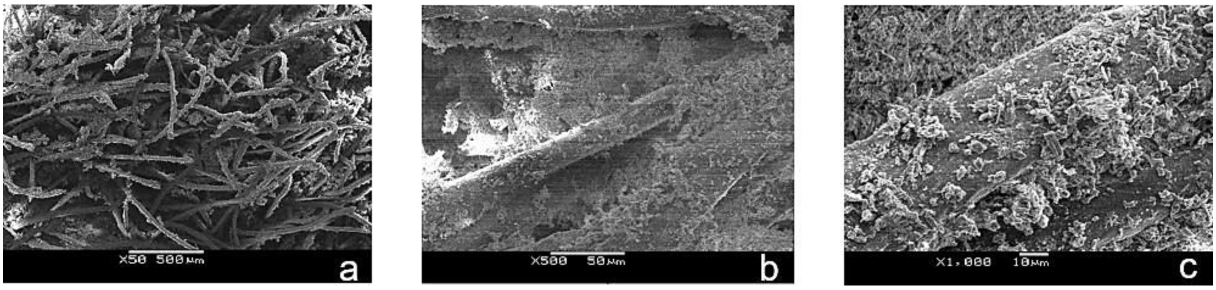

Fig. 4: Microphotographs of P1 polyester non-woven fabric with a mass per unit area of 150 g/m^2 in a gypsum matrix.

For the same non-woven fabric placed in a cement matrix, the improvement in bending strength was less than 20 %. Placement of the W1 wool non-woven fabric with a lower mass per unit area 280 g/m^2 in the gypsum sample improved the flexural strength by 30 % compared to the reference sample, while in the case of placing the same non-woven fabric in the cement matrix, the flexural strength was lower by 20 % than the sample without reinforcement. Worse results of reinforcement of the cement matrix than the gypsum matrix may be caused by a finer particle of the gypsum mortar than the cement one. The cement mortar contained aggregates with a diameter of up to 500 µm, which blocked the pores of the non-woven fabric and prevented its further penetration, Fig. 1.

Due to the lower strength of wool nonwovens than polyester nonwovens, additional steps are being considered in the future, such as sewing nonwovens. In this way, the structure of nonwovens can be changed, which are additionally reinforced with yarn, and thus their strength properties will increase. In addition, bad cooperation, especially with the cement matrix, and the lack of proper penetration through the non-woven fabric means that the phenomenon of plate reinforcement practically does not occur, due to the poor cooperation of the part located above and below the non-woven fabric. One of the solutions aimed at eliminating such a phenomenon may be to perforate the non-woven fabric, which would ensure better cooperation of the upper and lower parts of the matrix.

5 Summary

Placement of non-woven fabrics made of waste materials - wool and polyester - in cement and gypsum boards resulted in an improvement in density and thermal conductivity coefficient λ compared to reference samples. The largest decrease in the λ coefficient was recorded in the case of nonwovens made of wool.

A relationship was observed between the size of the pores and the mass per unit area of the nonwoven fabrics. They translated into cooperation with cement and gypsum - a decrease in the mass per unit area and an increase in the characteristic opening size facilitated the permeation of the mortar between the fibers and better anchoring in the depth of the non-woven fabric, which allowed to obtain higher values of composite bending strength.

The gypsum matrix showed better affinity to nonwovens, which could be related to its finer granulation. The obtained results allow us to consider the applied solutions as possible to be introduced in the future. Further stages of work should focus on stitching nonwovens and perforating them in order to change the structure of the nonwovens themselves and increase the cooperation of the upper and lower matrix plates.

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