

Research Article

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The effects of various parameters on the strengths of adhesives layer in a lightweight floor system

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Abstract: The article presents the results of shear and tensile strength of deformable cement adhesives, reinforced by fiberglass mesh with a different weight in a lightweight floor system without screeds. The substrate under adhesive was EPS and XPS thermal insulation. Tests were carried out in dry, wet conditions as well as during freezing and thawing. On their basis, it can be concluded that the larger contact surface of the EPS thermal insulation with the deformable adhesive C2S1 increases the adhesive's tensile strength. This surface is not important using C2S2 adhesives or when the substrate is made from rough insulation XPS. It was generally found that the higher weight of the fiberglass mesh in deformable cement adhesives has a more favorable effect on their shear strength. Water absorption does not significantly affect the adhesion of terracotta, and in some configurations of components in this system increases it. The adhesive with the symbol C2S2 compared to C2S1 has a higher tensile and shear strength using the same materials. Frost conditions do not allow for long-term use of this type of floor construction in snow and ice protection systems. This experimental research shows that an economical solution with optimal strength consists of XPS insulation, 205 g/m² mesh, C2S1 adhesive.

Keywords: light floor; tensile strength; shear strength; deformable adhesives

1 Introduction

At the moment, the light floor system is not a commonly used solution. It is worth popularizing due to many advantages, including:

- the low weight of a light floor allows installation it on ceilings with low load-bearing capacities (e.g. wooden) or where permanent loads should be reduced,
- the small thickness of the floor (no screeds, thicknesses 5-6cm in the light floor system) is important when renovating or modernizing rooms, due to the minimum dimension in the door light,
- the system is can be used for underfloor heating, in which, due to the lack of screed, we have lower thermal inertia of the floor, and this effects increasing the heat density flux (thermal efficiency), what confirmed in [1],
- due to the high efficiency and low thermal inertia, this type of floor is a universal heating and cooling model, which, as described in [2] should be the result of the latest research of scientists. These features are useful in devices using renewable energy sources (RES),
- there is no long process of binding concrete (floor no require screed), and this accelerates the commissioning of the investment.

The use of two components - adhesive and mesh layer as a replacement for cement or anhydrite screeds is a characteristic feature of this floor construction. Previous investigations of the layer system shown in Figure 1 and described in [3] have proved the need to use a glass fibre mesh.

Building boards are characterized by a similar construction used as thermal insulation under ceramic tiles. They are made on the core of extruded XPS polystyrene with a two-sided coating of modified cement mortar, reinforced with a fabric or a glass fibre mesh. Building boards are placed on the market based on European Technical Assessments [4] and National Technical Approvals [5]. In accordance with the assessment, or technical approval procedure, two strength tests are carried out, confirming the required technical and useful properties, before placing the product on the market:

- compressive strength at 10% deformation,
- tensile strength, perpendicular to the face.

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Declared properties depend on the product manufacturer, and they reach an amount not less than 0.20 MPa [6] in the case of compressive stresses and tensile strength. Made in 2017/2018 and described in [3, 7], tests of the mechanical light-floor system's strength were carried out using one type of C2 TE S1 cement adhesive and mesh with 335 g/m² weight. Through this procedure, the necessary information regarding the shear and tensile stress of the commonly available cement adhesive (not modified by the mortar manufacturers), was obtained. Standard [8] gives the adhesive the symbol C2, describing it as cement adhesive with increased parameters. Normally bonding adhesive are marked with the symbol C1. According to the standard [8], their minimum adhesion is ≥ 0.5 MPa. The cement adhesive type C2 must meet the additional high adhesion requirements of ≥ 1.0 MPa. It is important to emphasize that these values refer to the placement of ceramic tiles on a concrete substrate, in accordance with the standard [9]. Special requirements are characterized for adhesives with the symbols S1 and S2, where S1 is a deformable adhesive within the limits of ≥ 2.5 mm and < 5 mm, and S2 is an adhesive with a high deformability ≥ 5 mm. In the experimental tests described here, only C2 cement adhesive was adopted on the non-standard EPS and XPS thermal insulation substrates, with variable formability of S1 or S2. The article publishes the latest results of experimental research, where it was decided to check whether the use of cement adhesive mortar with the highest deformability (type C2S2) and various types of glass fibre mesh would have a significant impact on the selected parameters of the mechanical strength of the floor, without screeds.

For statistical purposes, the tests of adhesion and shear strength of the C2S1 adhesive, with the so-called "armored" mesh and a weight of 320 g/m², were repeated. In addition, the influence of other fibreglass mesh weights on the possible changes in strength properties of the C2S1 mortar was checked. Apart from tests in dry conditions, all panels were tested 21 days in water, in accordance with the standard [9]. In addition, frost resistance tests of 5×5 cm terracotta tiles attached to rough thermal insulation XPS 300, using C2S2 adhesive on fibreglass mesh, and weighing 145 and 205 g/m², were conducted. These tests were carried out after 25 and 50 cycles (3 samples each) of freezing and thawing, in accordance with the procedure described in [3]. This was done in order to initially verify the possibility of using this type of adhesive in the winter on a critical substrate, in the form of thermal insulation boards.

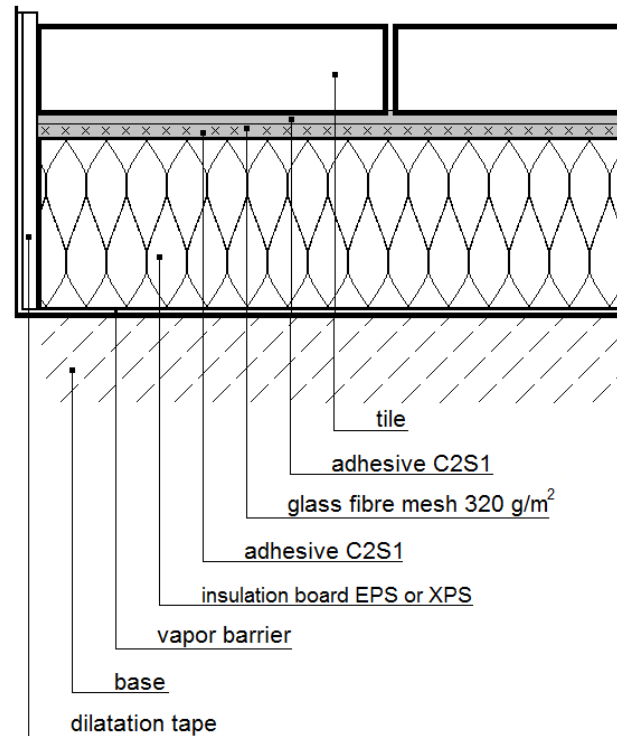


Figure 1: Cross-section of a light floor without screeds with XPS or EPS thermal insulation

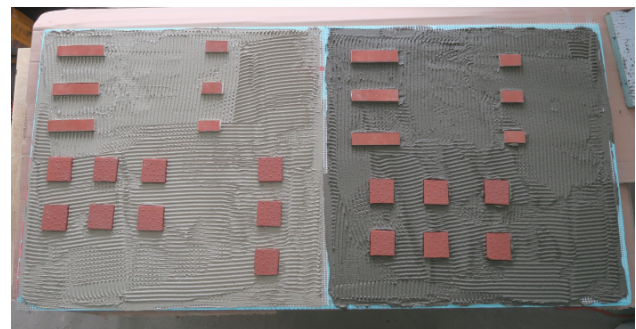


Figure 2: An example of a research stand, for adhesion measurements, using the pull-off method and shear strength tests, by PressoMess

2 Research methodology

The plates shown in Figure 2 were fabricated for research in the Elektra Kardo Białystok. After 28 days of seasoning at a temperature of approximately 20°C, they were transported to the Sika Poland laboratory for strength tests.

The measurements of the tensile and shear strength of stuck terracotta samples were carried out in accordance with the stated procedure. This was done on the machines described in [3]. The substrate consisted of XPS 300 insulating boards with a rough surface of 600 × 1250 mm and

an EPS 200 hydro with $500 \times 1000\text{mm}$. Terracotta tiles were attached on one half of each panel, using C2S1 cement mortar and C2S2 on the other, with reinforcement on both plates from the fibreglass mesh. The pull-off method was made in accordance with the recommendations of the standard [9], and the measurements of shear strength from PressoMess manufacturer's instructions. Because three types of mesh were used, the following 6 test sets were prepared with adhesives C2S1 Ceram 255, and C2S2 Schonox Q12:

- 3 pieces XPS board (rough) with 145, 205 and 320 g/m^2 glass fibre mesh
- 3 pieces EPS hydro board with 145, 205 and 320 g/m^2 glass fibre mesh

The photos of the preparing and measuring stands during tests are shown in Figure 3 and 4. Cross-sections of the lightweight floor stand are placed with the insulation boards (XPS and EPS), and a ceramic tiled floor, in order to research potential detachment and shear forces in the two adhesives, as shown in Figure 5.

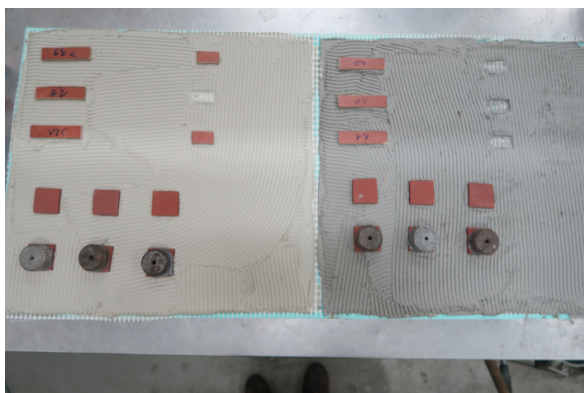


Figure 3: Preparing the stand to measure an adhesion



Figure 4: PressoMess for shear strength testing

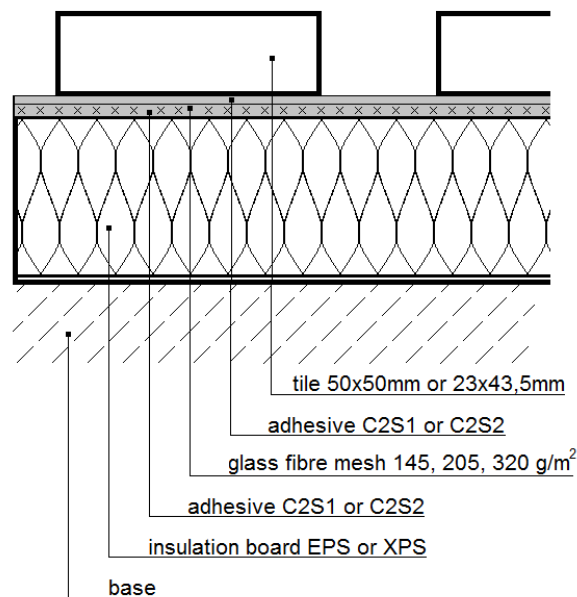


Figure 5: Cross-sections of the lightweight floor stand with insulation boards EPS and XPS with ceramic tile floor, in order to research of detachment and shear forces in two adhesives C2S1 & C2S2 and three fibreglass meshes

3 The research results

All test results are presented in the following tables.

Table 1 – dry and wet tests:

Model $A_{s,n}$ – results σ_s and σ_n based on EPS with C2S1 & C2S2,

Model $B_{s,n}$ – results σ_s and σ_n based on XPS with C2S1 & C2S2,

Model C_s – results τ_s based on EPS with C2S1 & C2S2,

Model D_s – results τ_s based on XPS with C2S1 & C2S2.

Table 2 – frost resistance tests in 25 and 50 cycles freezing and thawing:

Model A_m – results σ_m based on XPS with C2S2, where:

σ_s – tensile strength, dry condition

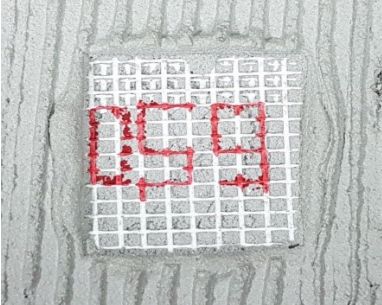
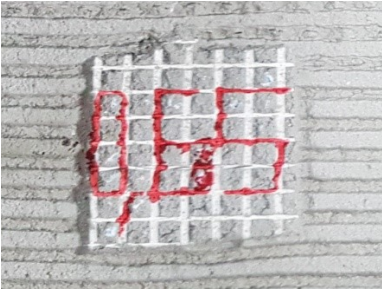

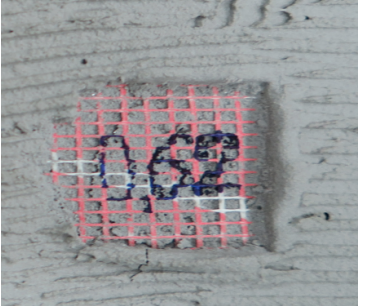


σ_n – tensile strength, wet condition

σ_m – tensile strength, frost resistance

τ_s – shear strength

Description in tables all forces [kN] only in a dry state.

Table 1: Test results in a dry and wet condition

Model A _{s,n} (with EPS insulation)	
– C2S1, with glass fibre mesh 145 g/m ² [MPa]	
	Sample Nr
	1. $\sigma_s = 0.21$
	2. $\sigma_s = 0.24$
	3. $\sigma_s = 0.24$
	1. $\sigma_n = 0.25$
	2. $\sigma_n = 0.24$
	3. $\sigma_n = 0.31$
	Average result
	$\sigma_s=0.23$
	$\sigma_n=0.27$
Most cohesive separation inside of adhesive, average force 0.57 kN	
– C2S1, with glass fibre mesh 205 g/m ² [MPa]	
	Sample Nr
	1. $\sigma_s = 0.26$
	2. $\sigma_s = 0.30$
	3. $\sigma_s = 0.24$
	1. $\sigma_n = 0.24$
	2. $\sigma_n = 0.22$
	3. $\sigma_n = 0.25$
	Average result
	$\sigma_s=0.27$
	$\sigma_n=0.24$
Most cohesive separation inside of adhesive, average force 0.66 kN	
– C2S1, with glass fibre mesh 320 g/m ² [MPa]	
	Sample Nr
	1. $\sigma_s = 0.18$
	2. $\sigma_s = 0.18$
	3. $\sigma_s = 0.23$
	1. $\sigma_n = 0.17$
	2. $\sigma_n = 0.21$
	3. $\sigma_n = 0.19$
	Average result
	$\sigma_s=0.20$
	$\sigma_n=0.19$
Cohesive separation inside of adhesive, average force 0.50 kN	
Model B _{s,n} (with XPS insulation)	
– C2S1, with glass fibre mesh 145 g/m ² [MPa]	
	Sample Nr
	1. $\sigma_s = 0.25$
	2. $\sigma_s = 0.21$
	3. $\sigma_s = 0.27$
	1. $\sigma_n = 0.19$
	2. $\sigma_n = 0.30$
	3. $\sigma_n = 0.25$
	Average result
	$\sigma_s=0.24$
	$\sigma_n=0.25$
Cohesive separation inside of adhesive, average force 0.60 kN	
– C2S1, with glass fibre mesh 205 g/m ² [MPa]	
	Sample Nr
	1. $\sigma_s = 0.25$
	2. $\sigma_s = 0.27$
	3. $\sigma_s = 0.25$
	1. $\sigma_n = 0.27$
	2. $\sigma_n = 0.23$
	3. $\sigma_n = 0.25$
	Average result
	$\sigma_s=0.26$
	$\sigma_n=0.25$
Most cohesive separation inside of adhesive, average force 0.64 kN	
– C2S1, with glass fibre mesh 320 g/m ² [MPa]	
	Sample Nr
	1. $\sigma_s = 0.23$
	2. $\sigma_s = 0.24$
	3. $\sigma_s = 0.30$
	1. $\sigma_n = 0.24$
	2. $\sigma_n = 0.26$
	3. $\sigma_n = 0.22$
	Average result
	$\sigma_s=0.26$
	$\sigma_n=0.24$
Cohesive separation inside of adhesive, average force 0.64 kN	

– C2S2, with glass fibre mesh 145 g/m² [MPa]

Cohesive separation inside of adhesive, average force 0.77 kN

Sample Nr
1. $\sigma_s = 0.32$
2. $\sigma_s = 0.29$
3. $\sigma_s = 0.31$
1. $\sigma_n = 0.36$
2. $\sigma_n = 0.35$
3. $\sigma_n = 0.30$
Average result
$\sigma_s=0.31$
$\sigma_n=0.33$

– C2S2, with glass fibre mesh 205 g/m² [MPa]

Sample Nr

– C2S2, with glass fibre mesh 145 g/m² [MPa]



Adhesive separation from XPS,
average force 0.70 kN

Sample Nr

1. $\sigma_s = 0.31$

2. $\sigma_s = 0.25$

3. $\sigma_s = 0.28$

1. $\sigma_n = 0.35$

2. $\sigma_n = 0.33$

3. $\sigma_n = 0.30$

Average result

$\sigma_s = 0.28$

$\sigma_n = 0.32$

– C2S2, with glass fibre mesh 205 g/m² [MPa]



Most cohesive separation inside of
adhesive, average force 0.67 kN

Sample Nr

1. $\sigma_s = 0.28$

2. $\sigma_s = 0.26$

3. $\sigma_s = 0.27$

1. $\sigma_n = 0.19$

2. $\sigma_n = 0.26$

3. $\sigma_n = 0.28$

Average result

$\sigma_s = 0.27$

$\sigma_n = 0.25$

– C2S2, with glass fibre mesh 320 g/m² [MPa]



Cohesive separation inside of
adhesive, average force 0.74 kN

Sample Nr

1. $\sigma_s = 0.32$

2. $\sigma_s = 0.25$

3. $\sigma_s = 0.32$

1. $\sigma_n = 0.37$

2. $\sigma_n = 0.37$

3. $\sigma_n = 0.36$

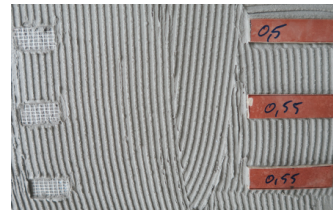
Average result

$\sigma_s = 0.30$

$\sigma_n = 0.37$

Model C_s (with EPS insulation)

– C2S1, with glass fibre mesh 145 g/m² [MPa]



Cohesive separation inside of
adhesive

Sample Nr

1. $\tau_s = 0.50$

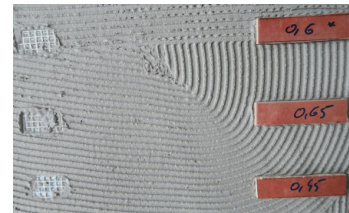
2. $\tau_s = 0.55$

3. $\tau_s = 0.55$

Average result

$\tau_s = 0.53$ MPa

– C2S1, with glass fibre mesh 205 g/m² [MPa]



Most cohesive separation inside of
adhesive

Sample Nr

1. $\tau_s = 0.65$

2. $\tau_s = 0.65$

3. $\tau_s = 0.45$

Average result

$\tau_s = 0.58$ MPa

– C2S1, with glass fibre mesh 320 g/m² [MPa]



Most cohesive separation inside of
adhesive

Sample Nr

1. $\tau_s = 0.60$

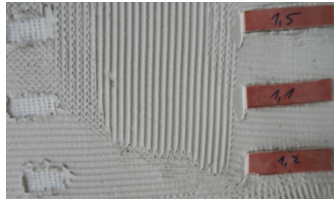
2. $\tau_s = 0.65$

3. $\tau_s = 0.50$

Average result

$\tau_s = 0.58$ MPa

– C2S2, with glass fibre mesh 145 g/m² [MPa]



Sample Nr

1. $\tau_s = 1.50$ 2. $\tau_s = 1.10$ 3. $\tau_s = 1.20$

Average result $\tau_s = 1.27 \text{ MPa}$

Most cohesive separation inside of
adhesive

– C2S2, with glass fibre mesh 205 g/m² [MPa]



Sample Nr

1. $\tau_s = 1.25$ 2. $\tau_s = 1.10$ 3. $\tau_s = 1.00$

Average result $\tau_s = 1.12 \text{ MPa}$

Most cohesive separation inside of
adhesive

– C2S2, with glass fibre mesh 320 g/m² [MPa]



Sample Nr

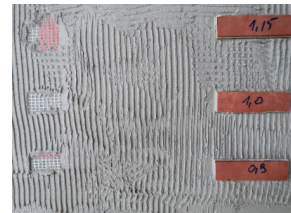
1. $\tau_s = 1.60$ 2. $\tau_s = 1.40$ 3. $\tau_s = 1.15$

Average result $\tau_s = 1.38 \text{ MPa}$

Most cohesive separation inside of
adhesive

Model D_s (with XPS insulation)

– C2S1, with glass fibre mesh 145 g/m² [MPa]



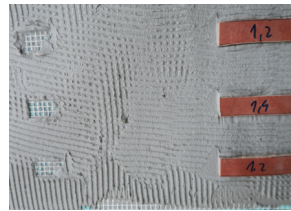
Sample Nr

1. $\tau_s = 1.15$ 2. $\tau_s = 1.00$ 3. $\tau_s = 0.90$

Average result $\tau_s = 1.02 \text{ MPa}$

Cohesive separation inside of
adhesive

– C2S1, with glass fibre mesh 205 g/m² [MPa]



Sample Nr

1. $\tau_s = 1.20$ 2. $\tau_s = 1.40$ 3. $\tau_s = 1.20$

Average result $\tau_s = 1.27 \text{ MPa}$

Most adhesive separation from XPS

– C2S1, with glass fibre mesh 320 g/m² [MPa]



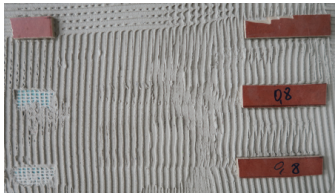
Sample Nr

1. $\tau_s = 1.10$ 2. $\tau_s = 1.00$ 3. $\tau_s = 1.00$

Average result $\tau_s = 1.03 \text{ MPa}$

Most cohesive separation inside of
adhesive

– C2S2, with glass fibre mesh 145 g/m² [MPa]



- Sample Nr
- 1. $\tau_s \geq 2.0$ no detachment
 - 2. $\tau_s = 0.80$
 - 3. $\tau_s = 0.80$

Average result
 $\tau_s = 1.20$ MPa

Adhesive separation from XPS

– C2S2, with glass fibre mesh 205 g/m² [MPa]

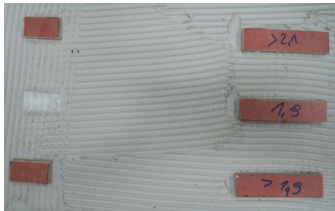


- Sample Nr
- 1. $\tau_s = 1.50$
 - 2. $\tau_s = 1.30$
 - 3. $\tau_s = 1.60$

Average result
 $\tau_s = 1.47$ MPa

Most adhesive separation from XPS

– C2S2, with glass fibre mesh 320 g/m² [MPa]



- Sample Nr
- 1. $\tau_s > 2.10$
 - 2. $\tau_s = 1.90$
 - 3. $\tau_s > 1.90$

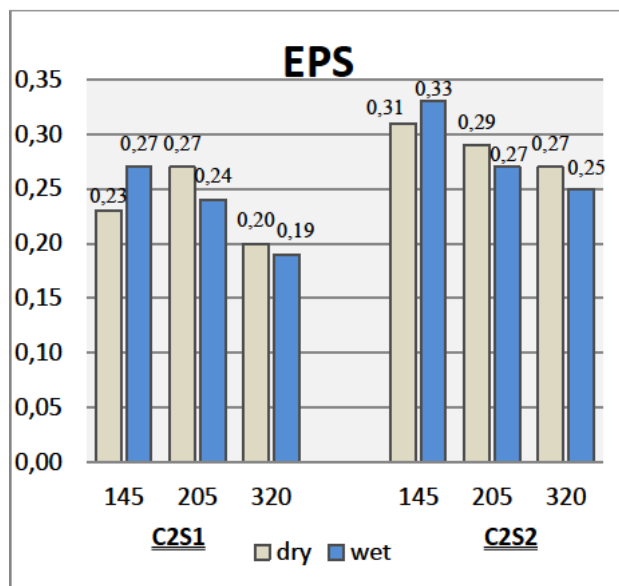
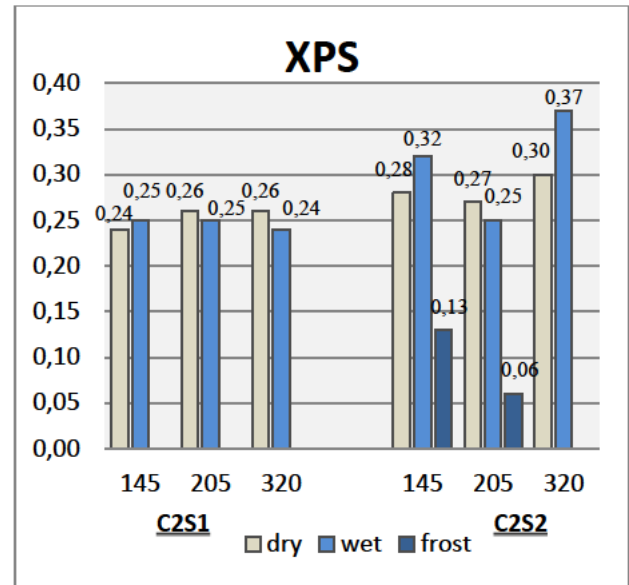
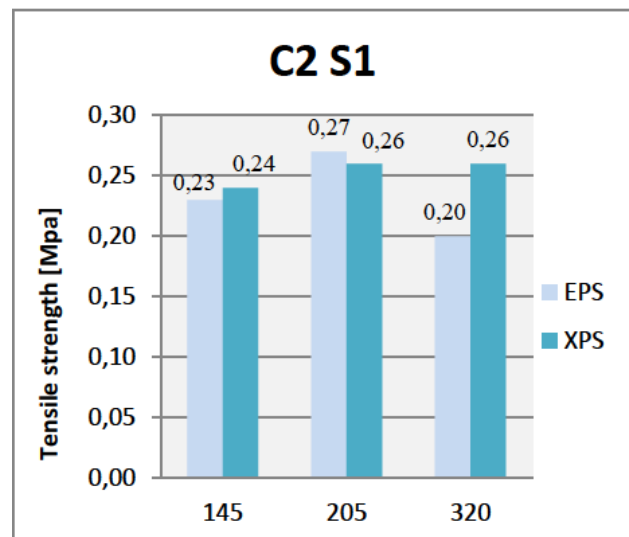
Average result
 $\tau_s \approx 2.00$ MPa

Cohesive separation inside of adhesive

Table 2: The results of frost resistance tests

Model A _m (with XPS insulation)	
– C2S2, with glass fibre mesh 145 g/m ² , 25 cycles [MPa]	
Adhesive separation of glue cement mortar from terracotta tile, average force 0.32 kN	Sample Nr
	1. $\sigma_m = 0.14$
	2. $\sigma_m = 0.16$
	3. $\sigma_m = 0.09$
	Average result $\sigma_m = 0.13$
– C2S2, with glass fibre mesh 205 g/m ² , 50 cycles [MPa]	
Adhesive separation of glue cement mortar from terracotta tile, average force 0.15 kN	Sample Nr
	1. $\sigma_m = 0.04$
	2. $\sigma_m = 0.07$
	3. $\sigma_m = 0.06$
	Average result $\sigma_m = 0.06$

The terracotta tensile strength results for the various types of glass fibre mesh, insulation base and adhesives are shown in Figures 6-9, and the shear strength in Figures 10-11.

**Figure 6:** Average results of the pull-off method; comparing the same EPS insulation to different mesh & adhesive & conditions (dry-wet)**Figure 7:** Average results of the pull-off method; comparing the same XPS insulation to different mesh & adhesive & conditions (dry-wet-frost)**Figure 8:** Average results of the pull-off method; comparing the same adhesive C2S1 to different mesh & insulation

The difference in tensile strength in various EPS or XPS insulation bases, using the same weight of fibreglass mesh in C2S1 adhesive and C2S2, is in the range of 5-10%, as shown in Figure 6 and 7. A 20% greater discrepancy and higher adhesion were noticed only when using a 320 g/m² mesh on an XPS substrate. This is confirmed in [3]. Figure 8 and 9 show how the use of different types of C2S1 or C2S2 adhesive influences identical undercoats and reinforcing meshes. Differences in stress during the detachment of samples are 15-26%, and cement adhesive C2S2 has

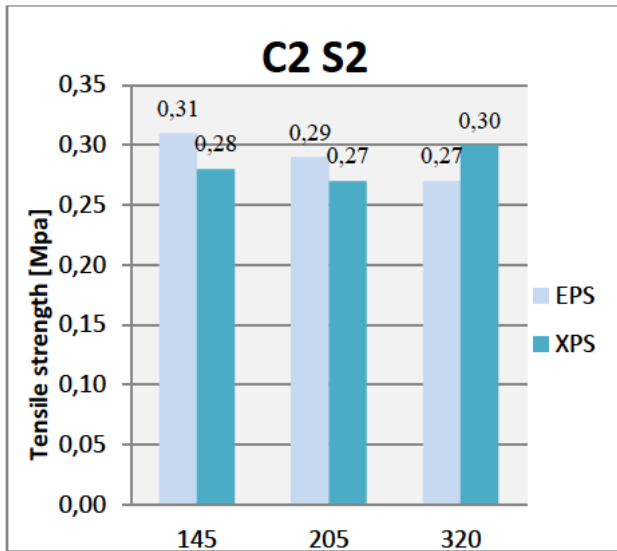


Figure 9: Average results of the pull-off method; comparing the same adhesive C2S2 to different mesh & insulation

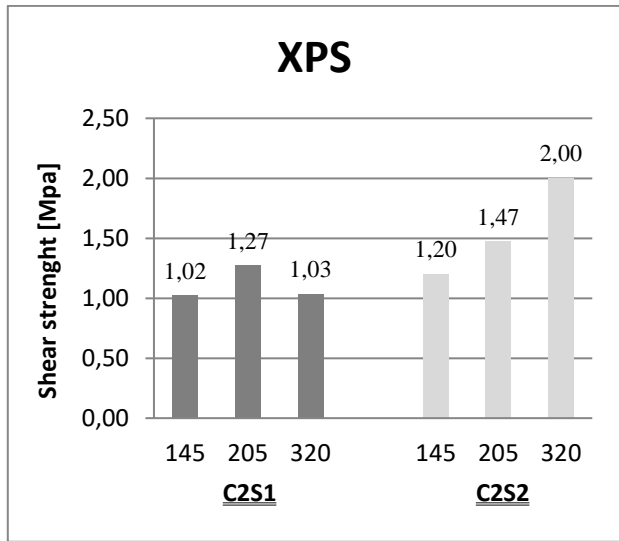


Figure 11: Average results of the shear strength tests; comparing the same XPS insulation to different mesh & adhesive

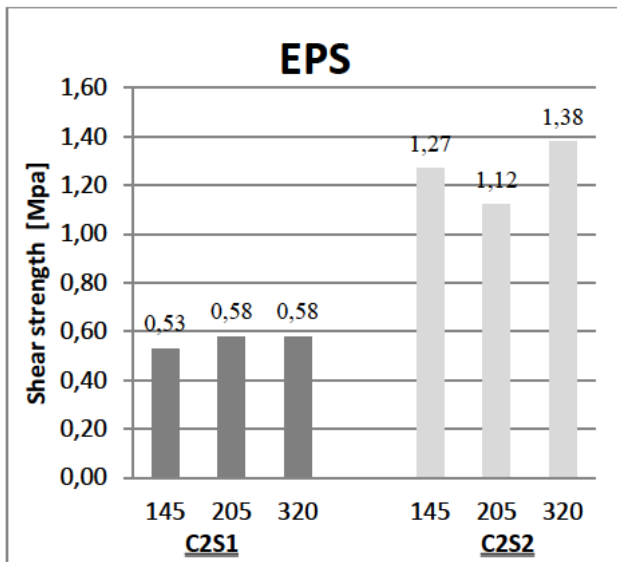


Figure 10: Average results of the shear strength tests; comparing the same EPS insulation to different mesh & adhesive

better adhesion. Only with a mesh weight of 205 g/m², deviations are smaller 3-7%.

Interestingly, the amount of adhesive tensile strength may depend on the total area of the gaps in the fibreglass mesh used for EPS insulation (dry conditions). It amounts to 1590, 1710 and 1430 mm² for 145, 205 and 320 g/m² respectively (Figure 12-14). In a mesh 320 g/m², the contact surface of the adhesive and thermal insulation is the least. This can affect the fact that in EPS thermal insulation, with a larger contact surface between the adhesive and thermal insulation, the tensile force is higher. This is

confirmed by the results of research using various types of mesh on EPS insulation in the article [10], where it was found that the use of 320 g/m² mesh (armored mesh) does not increase the system's tensile strength. The results of the present article show that this phenomenon does not occur in XPS insulation with a different material surface structure than EPS and for adhesives with higher C2S2 deformability. Here the surface of the gaps in mesh does not affect significant changes in the tensile strength of cement adhesives (Figure 6-9).

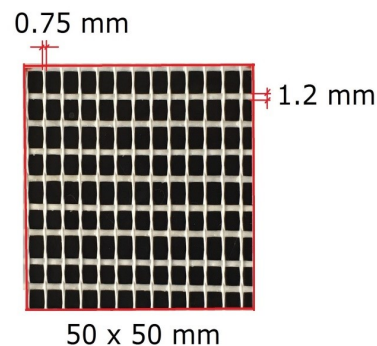


Figure 12: The total area of the gaps is equal to 1590 mm² (for 145 g/m² the fibreglass mesh)

When comparing experimental conditions, generally, the absorbability of light floors does not have a major impact on their strength, and even in a moist environment, the tensile strength is increased by 20%, as noted in Figure 7, using an XPS board, the 320 g/m² mesh, and a C2S2

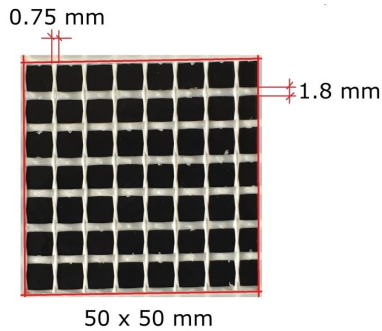


Figure 13: The total area of the gaps is equal to 1710 mm² (for 205 g/m² the fibreglass mesh)

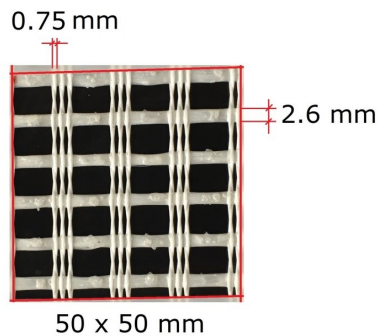


Figure 14: The total area of the gaps is equal to 1430 mm² (for 320 g/m² the fibreglass mesh)

adhesive. A significant decrease in tensile strength during frost resistance tests is shown in Figure 7. Standard tensile tests with 25 cycles of freezing and thawing have half this strength in relation to dry conditions. When we apply non-standard 50 cycles, the strength drops to 0.06 MPa.

Higher mesh weight generally increases the shear strength of deformable cementitious adhesives. This can be seen in figures 10 and 11 in C2S1 adhesives on EPS insulation and C2S2 on XPS insulation. During shear stress tests, the EPS substrate had 2 times the higher bond strength, using C2S2 adhesive relative to C2S1, independent of the meshes as shown in Figure 10. The same result was obtained by comparing the EPS and XPS insulation, in favor of the latter in the C2S1 adhesive. Smaller differences in stresses occur in the C2S2 adhesives and XPS insulation - 15-20%. Only when applying the 320 g/m² mesh, the disproportion increases by a multiple of 2, and the shear strength is 2 MPa, as depicted in Figure 11.

4 Conclusions

The presented results of the terracotta tensile strength tests in a light floor system prove that:

- Absorbability does not significantly affect the adhesion of terracotta, and in some configurations increases it,
- Frost conditions contribute to a significant 2-times the reduction of this strength on C2S2 adhesive, which is also confirmed by the results obtained in [3] using C2S1. The standard test proves sufficient adhesion of tiles according to [11], but non-standard tests with 50 cycles of freezing and thawing do not meet the technical conditions. This does not allow for long-term, trouble-free use of this type of floor construction in snow and ice protection systems,
- Twice the better shear strength is a result of using identical materials (XPS, C2S1, 320 g/m²), described in this article in relation to [7], proving that the precise application of the tile assembly rules, adhesive application, and the structure of the insulating base, all have a significant impact on strength parameters of light floors,
- The same is confirmed by the results of the pull-off method, where the results described in this article compared to [7] are 30% higher for EPS and 60% greater for XPS,
- The tensile strength of C2S1 adhesive is higher when the gaps of the fibreglass mesh used have a larger contact surface with EPS insulation. This is not important when using C2S2 adhesives or the substrate is from rough insulation XPS.
- Generally, it can be stated that the higher grammage of the fibreglass mesh in deformable cement adhesives on the EPS and XPS insulation substrate contributes to the increase of shear strength of these adhesives.
- An adhesive with the symbol C2S2 in relation to C2S1 has a higher tensile and shear strength with the same mesh weight or type of base insulating.

OPTIMAL LIGHT FLOOR MODEL FOR TESTING TENSION STRENGTH

We achieve the best results by using:

- EPS insulation, 145 g/m² mesh, C2S2 adhesive = 0.31 MPa,

The worst results when using:

- EPS insulation, 320 g/m² mesh, C2S1 adhesive = 0.20 MPa.

For the optimal solution (economically profitable with a good result, meeting the criteria of pull-off strength, and equal to 0.26 MPa) the floor constructions consisting of:

1. XPS insulation, 205 g/m² mesh, C2S1 adhesive.

OPTIMAL LIGHT FLOOR MODEL FOR TESTING SHEAR STRENGTH

We achieve the best results by using:

- XPS insulation, 320 g/m² mesh, C2S2 adhesive = 2.00 MPa,

The worst results when using:

- EPS insulation, 145 g/m² mesh, C2S1 adhesive, = 0.53 MPa.

For the optimal solution (economically profitable with a good result, meeting even the criteria for stronger dispersion adhesives acc. [6], equal to 1.27 MPa) a floor construction composed of the following can be considered:

1. XPS insulation, 205 g/m² mesh, C2S1 adhesive.

After analyzing the tests of tensile and shear strength, it can be concluded that the optimal lightweight floor construction consists of rough XPS thermal insulation boards, on which terracotta tiles were directly attached, using cement adhesive type C2S1 with an embedded mesh of 205 g/m² weight.

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