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Review Article

Regression of The Tensile Strength of Deformable Adhesive From Thermal Insulation Density In The Lightweight Floor System

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Abstract

Based on the experimental test results of the tensile strength of the C2S1 adhesive, the regression and strength of connections between this adhesive and the thermal insulation substrate were evaluated. Two types of insulation were adopted, i.e. extruded polystyrene XPS and expanded EPS, respectively, with a density of 34 and 28kg/m^3. The dependence of pull-off strength was tested at various test conditions, namely wet, dry, and mixed. Selected statistical analysis based on correlations and relations also gives information on how an increase in the density of thermal insulation by 1kg/m^3, influences an increase in tensile strength of the pull-off method cement adhesive C2S1, in various test conditions. The obtained data also allowed for verifying the relationship (regression) hypothesis between the pull-off strength of the C2S1 adhesive, and the type of thermal insulation EPS and XPS with different densities and under different user conditions.

Keywords: Deformable Adhesive C2S1; Regression; Lightweight Floor System; Thermal Insulation

Introduction

The article is a continuation of the statistical analysis presented in [1], and based on experimental research [2-4]. In the paper [1] it has been proven statistically that the higher tensile and shear strength is achieved by using thermal insulation with a higher density in all humidity conditions in a lightweight floor system (LFS). In this scenario, the extruded XPS polystyrene was compared to the expanded EPS. In addition, the minimum tensile and shear strength of the C2S1 adhesive was determined statistically, which sets the tile floor with the thermal insulation substrate EPS or XPS, with different humidity conditions in LFS. It is worth noting that experimental research was carried out only on various types of rough insulation substrates. Photos of research stands have been described in [1] and in (Figure 1).The vertical section of a lightweight floor system is shown once again in (Figure 2).

Figure 1: Measuring stand DYNA Z16 Leo1 for the pull-off method.

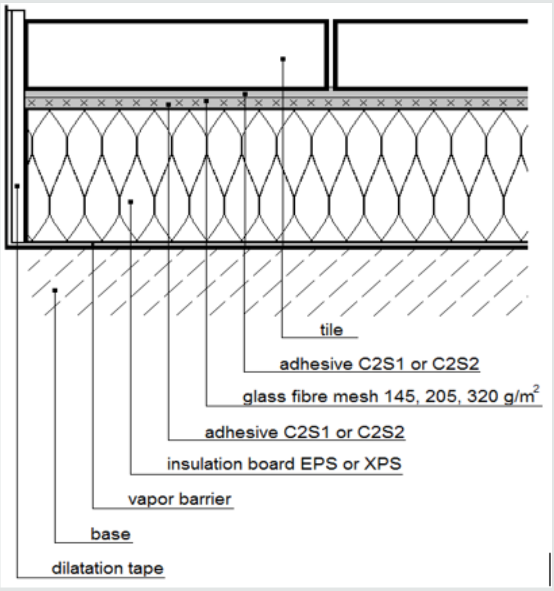

Figure 2: Cross-section of a lightweight floor system with XPS or EPS thermal insulation.

This article verifies the overall hypotheses, assesses the strength of connections, and checks the relationship between the pull-off strength of the deformable adhesive and the type of insulating base in dry, wet and mixed conditions according to [5,6]. Mixed conditions means that the results of dry and wet tests were analyzed as a whole.

Results of Calculation

In this aricle, the hypotheses, regression, and strengths of connections between the pull-off strength of the C2S1 adhesive and the density of EPS and XPS thermal insulation, have been verified.

Determining the dependence (regression) between the pull-off strength of the C2S1 adhesive and the type of thermal insulation EPS and XPS of different density in dry and wet conditions.

In order to check the relationship between the tested pull-off strength (in dry and wet conditions) of the lightweight floor system, and the type of thermal insulation EPS200 and XPS300, the method of mass phenomena in the form of linear regression was applied. A single method of least squares was used. An evacuated (loaded) variable is the tensile strength and the explanatory (weighting) density of thermal insulation. The pull-off strength data from the tests and the minimum density of materials used with a value of 28kg/m^3 in EPS and 34kg/m^3 in XPS are shown in Table 1. The estimation of the Y regression function with respect to X in the general population is the regression function y versus x in the random sample, having the following form:

Table 1: Pull-off strength data from dry and wet tests and the minimum density of materials used.

Nr	Pull-off dry and wet (y_j) [MPa]	Minimum density of insulation (x_j) [kg/m^3]	$x_j y_j$	y_j^2	x_j^2
1	0.196	28	5.488	0.038416	784
2	0.236	28	6.608	0.055696	784
3	0.196	28	5.488	0.038416	784
4	0.176	28	4.928	0.030976	784
5	0.164	28	4.592	0.026896	784
6	0.184	28	5.152	0.033856	784
7	0.184	28	5.152	0.033856	784
8	0.228	28	6.384	0.051984	784
9	0.208	28	5.824	0.043264	784
10	0.236	28	6.608	0.055696	784
11	0.236	28	6.608	0.055696	784
12	0.26	28	7.280	0.067600	784
13	0.236	28	6.608	0.055696	784
14	0.200	28	5.600	0.040000	784
15	0.184	28	5.152	0.033856	784
16	0.168	28	4.704	0.028224	784
17	0.164	28	4.592	0.026896	784
18	0.212	28	5.936	0.044944	784
19	0.188	28	5.264	0.035344	784
20	0.248	28	6.944	0.061504	784
21	0.216	28	6.048	0.046656	784
22	0.244	28	6.832	0.059536	784
23	0.200	28	5.600	0.040000	784
24	0.308	34	10.472	0.094864	1156

25	0.248	34	8.432	0.061504	1156
26	0.288	34	9.792	0.082944	1156
27	0.308	34	10.472	0.094864	1156
28	0.320	34	10.88	0.102400	1156
29	0.340	34	11.56	0.115600	1156
30	0.228	34	7.752	0.051984	1156
31	0.236	34	8.024	0.055696	1156
32	0.300	34	10.20	0.090000	1156
33	0.248	34	8.432	0.061504	1156
34	0.208	34	7.072	0.043264	1156
35	0.268	34	9.112	0.071824	1156
36	0.248	34	8.432	0.061504	1156
37	0.268	34	9.112	0.071824	1156
38	0.248	34	8.432	0.061504	1156
38	0.176	34	5.984	0.030976	1156
40	0.196	34	6.664	0.038416	1156
41	0.236	34	8.024	0.055696	1156
42	0.260	34	8.840	0.067600	1156
43	0.212	34	7.208	0.044944	1156
44	0.184	34	6.256	0.033856	1156
45	0.212	34	7.208	0.044944	1156
46	0.272	34	9.248	0.073984	1156
47	0.228	34	7.752	0.051984	1156
48	0.248	34	8.432	0.061504	1156
Sum	11.052	1494	347.184	2.630192	46932
Average	0.23025	31.125			

$$\hat{y} = a_y \times X + b_y$$

Where

$$a_y = \frac{n\Sigma x_j y_j - \Sigma x_j \Sigma y_j}{n\Sigma x_j^2 - (\Sigma x_j)^2}, b_y = \overline{y_j} - a_y \overline{x_j}$$

$$a_y = \frac{48 \times 347.184 - 1494 \times 11.052}{48 \times 46932 - (1494)^2} = 0.0074 \approx 0.007$$

$$b_y = 0.23025 - 0.0074 \times 31.125 = 0.000075$$

$$\hat{y} = 0.007x + 0.000075$$

From this conclusion, the increase in the density of thermal insulation by 1kg/m^3 increases the pull-off strength by approximately 0.007 MPa. This means that the pull-off method in mixed conditions (dry and wet) is higher when we apply XPS 300 insulation against EPS 200 by 0.04 MPa, considering the density of these materials Table 1.

Table 2: Correlation table with data

x y	Pull-off, dry	Pull-off, wet	Σ
average in EPS	0.2108	0.2024	0.4132
Average in XPS	0.2709	0.2224	0.4933
∑	0.4817	0.4248	0.9065

Table 3: Pull-off strength data from dry tests and minimum density of materials used.

Nr	Pull-off dry (y_j) [MPa]	Minimum insulation density (x_j) [kg/m^3]	$x_j y_j$	y_j^2	x_j^2
1	0.196	28	5.488	0.038416	784
2	0.236	28	6.608	0.055696	784
3	0.196	28	5.488	0.038416	784
4	0.176	28	4.928	0.030976	784
5	0.164	28	4.592	0.026896	784
6	0.184	28	5.152	0.033856	784
7	0.184	28	5.152	0.033856	784
8	0.228	28	6.384	0.051984	784

9	0.208	28	5.824	0.043264	784
10	0.236	28	6.608	0.055696	784
11	0.236	28	6.608	0.055696	784
12	0.260	28	7.280	0.067600	784
13	0.236	28	6.608	0.055696	784
14	0.308	34	10.472	0.094864	1156
15	0.248	34	8.432	0.061504	1156
16	0.288	34	9.792	0.082944	1156
17	0.308	34	10.472	0.094864	1156
18	0.320	34	10.88	0.102400	1156
19	0.340	34	11.56	0.115600	1156
20	0.228	34	7.752	0.051984	1156
21	0.236	34	8.024	0.055696	1156
22	0.300	34	10.20	0.090000	1156
23	0.248	34	8.432	0.061504	1156
24	0.208	34	7.072	0.043264	1156
25	0.268	34	9.112	0.071824	1156
26	0.248	34	8.432	0.061504	1156
27	0.268	34	9.112	0.071824	1156
28	0.248	34	8.432	0.061504	1156
Sum	**6.804**	**874**	**214.896**	**1.709328**	**27532**
Average	0.243	31.21429			

Table 4: Pull-off strength data from wet tests and minimum densities of materials used.

Lp.	Pull off dry (y_j) [MPa]	Minimum insulation density (x_j) [kg/m³]	$x_j y_j$	y_j^2	x_j^2
1	0.200	28	5.600	0.040000	784
2	0.184	28	5.152	0.033856	784
3	0.168	28	4.704	0.028224	784
4	0.164	28	4.592	0.026896	784
5	0.212	28	5.936	0.044944	784
6	0.188	28	5.264	0.035344	784
7	0.248	28	6.944	0.061504	784
8	0.216	28	6.048	0.046656	784
9	0.244	28	6.832	0.059536	784
10	0.200	28	5.600	0.040000	784
11	0.176	34	5.984	0.030976	1156
12	0.196	34	6.664	0.038416	1156
13	0.236	34	8.024	0.055696	1156
14	0.260	34	8.840	0.067600	1156
15	0.212	34	7.208	0.044944	1156
16	0.184	34	6.256	0.033856	1156
17	0.212	34	7.208	0.044944	1156
18	0.272	34	9.248	0.073984	1156
19	0.228	34	7.752	0.051984	1156
20	0.248	34	8.432	0.061504	1156
Sum	**4.248**	**620**	**132.288**	**0.920864**	**19400**
Average	**0.2124**	**31**			

Verification of the hypotheses regarding the relationship (regression) between the pull-off strength of the C2S1 adhesive, and the type of thermal insulation EPS and XPS, with different densities in dry and wet conditions.

In order to determine whether there is a significant relationship between the tested variables (wet and dry pull-off strength and thermal insulation density), the hypothesis of complete y/x regression should be verified. The hypothesis of the complete absence of regression - the F test, that is, the pull-off strength and thermal insulation density:

H_0: no regression; H_1: regression exists - right-handed

The F-Snedecor test was used for this purpose.

$F = \frac{MSR}{MSE}$, Where

$$MSR = SSR, SSR = \frac{\left(\Sigma x_j y_j - \frac{\Sigma x_j y_j}{n}\right)^2}{\Sigma x_j^2 - \frac{(\Sigma x_j)^2}{n}}, MSE = \frac{SSE}{n-2}, SSE = SST - SSR$$

$$SST == \Sigma y_j^2 - \frac{(\Sigma y_j)^2}{n} = 2.630192 - \frac{(11.052)^2}{48} = 0.085469$$

$$SSR = \frac{\left(347.184 - \frac{11.052 \times 1494}{48}\right)}{46932 - \frac{(1494)^2}{48}} = 0.0236$$

SSE = 0.085469 – 0.0236 = 0.06187

$$MSE = \frac{0.06187}{46} = 0.0013449$$

$$F = \frac{0.0236}{0.0013449} = 17.548$$

The right-handed critical area was determined from the F-Snedecor tables $F_{?,s1,s2,}$? = 0.05

$s_1 = 1$, $s_2 = n-2 = 48-2 = 46$

$F_{0,05,1.46} = 4.06$

The test result F = 17.548 falls within the designated critical area, so we reject H_0 in favor of H_1. This means that the value of pull-off strength in dry and wet conditions significantly depends on the density of thermal insulation at the level of significance of 0.05.

Evaluation of the strength of the connections between the tensile strength of the C2S1 adhesive and the density of thermal insulation EPS and XPS, based on the arithmetic mean of these variables.

In order to check the strength of variable associations, one should first determine their interdependencies by putting the H_0 hypothesis on the lack of this correlation and the H_1 hypothesis that it exists. The χ2 test was used to verify H_0.

$$x^2 = \Sigma_{i=1}^{k} \Sigma_{j=1}^{l} \frac{\left(n_{ij} - \hat{n}_{ij}\right)^2}{\hat{n}_{ij}}$$

$\hat{n}_{ij}$ – theoretical numbers calculated from the boundary distributions according to the formula

$$\hat{n}_{ij} = \frac{n_i \times n_j}{n}$$

Correlation table with data (Table 2)

$$\hat{n}_{11} = \frac{0.4132 \times 0.4817}{0.9065} = 0.2196$$

$$\hat{n}_{12} = \frac{0.4132 \times 0.4248}{0.9065} = 0.1936$$

$$\hat{n}_{21} = \frac{0.4933 \times 0.4817}{0.9065} = 0.2621$$

$$\hat{n}_{22} = \frac{0.4933 \times 0.4248}{0.9065} = 0.2312$$

$$x^2 = \frac{(0.2108 - 0.2196)^2}{0.2196} + \frac{(0.2024 - 1.936)^2}{1.936} + \frac{(0.2709 - 0.2621)^2}{0.2621} + \frac{(0.2224 - 0.2321)^2}{0.2321}$$

$$x^2 = 0.000353 + 0.0004 + 0.000295 + 0.000335 = 0.00138$$

A critical area was determined based on the right-handed hypothesis from the distribution tables x^2

s=(k-1)·(l-1) = (2-1)·(2-1) = 1 , $\chi^2_{0.05,\,1} = 3.8415$

The result of the x^2 test does not fit into the designated critical area, so there are no grounds to reject H_0. This means that we can not assume on a 95% certainty that there is a statistically significant relationship between the average durability of EPS and XPS insulation in dry and wet conditions.

Confirming the lack of correlation between the examined variables is the value of the Czuprow coefficient T_{xy}:

$$T_{xy} = \sqrt{\frac{x^2}{n\sqrt{(k-1)(l-1)}}} = \sqrt{\frac{0.0138}{0.9065(1)}} = 0.04 < 0.2 \quad \text{(no dependence)}$$

Determining the dependence (regression) between the strength of the pull-off method of the C2S1 adhesive, and the type of thermal insulation EPS and XPS only in dry conditions.

In order to check the relationship between the tested pull-off tensile strength only in dry conditions of the lightweight floor system, and the type of thermal insulation EPS200 and XPS300, the method of mass phenomena in the form of linear regression was applied. A single method of least squares was used. An evacuated (loaded) variable is the tensile strength and the explanatory (weighting) density of thermal insulation. The pull strength data from the tests and the minimum density of materials used with a value of 28kg/m³ in EPS and 34 kg/m³ in XPS are shown in Table 3. The estimation of the Y regression function with respect to X in the general population is the regression function y versus x in the random sample having the following form:

$\hat{y} = a_y\ x + b_y$

$$a_y = \frac{n\Sigma x_j y_j - \Sigma x_j \Sigma y_j}{n\Sigma x_j^2 - (\Sigma x_j)^2}, b_y = \overline{y_j} - a_y \overline{x_j}$$

$$a_y = \frac{28\times 214.896 - 874\times 6.804}{28\times 27532-(874)^2} = 0.00273 \approx 0.01$$

$$b_y = 0.243 - 0.01\times 31.21429 = 0.0691429$$

From this conclusion, the increase in density of thermal insulation by 1 kg/m[3] increases the pull-off strength in dry conditions by 0.01 MPa. This means that the pull-off method in dry conditions is higher when using XPS 300 insulation against EPS 200 by 0.06 MPa, bearing in mind the adopted density of these materials.

Verification of the hypotheses regarding dependence (regression) between the pull-off strength of the C2S1 adhesive, and the type of thermal insulation EPS and XPS only in dry conditions.

In order to determine whether there is a significant relationship between the tested variables (dry pull-off strength and thermal insulation density), the hypothesis of the complete y/x regression should be verified. The hypothesis of complete absence of regression - F test, i.e. pull-off strength and thermal insulation density:

H_0: no regression; H_1: regression exists - right-handed

The F-Snedecor test was used for this purpose.

$$F = \frac{MSR}{MSE}, \text{ where } MSR = SSR, SSR = \frac{\left(\Sigma x_j y_j - \frac{\Sigma x_j y_j}{n}\right)^2}{\Sigma x_j^2 - \frac{(\Sigma x_j)^2}{n}}, MSE = \frac{SSE}{n-2}, SSE = SST - SSR$$

$$SST = \Sigma y_j^2 - \frac{(\Sigma y_j)^2}{n} = 1.709328 - \frac{(6.804)^2}{28} = 0.0055956$$

$$SSR = \frac{\left(214.896 - \frac{6.804.874}{28}\right)^2}{27532 - \frac{(874)^2}{28}} = 0.02521$$

$$SSR = \frac{\left(214.896 - \frac{6.804.874}{28}\right)}{19400 - \frac{(874)^2}{28}} = 0.02521$$

SSE = 0.055956 – 0,02521 = 0.03075

$$MSE = \frac{0.03075}{26} = 0.0011825$$

$$F = \frac{0.0236}{0.0013449} = 21.319$$

The right-handed critical area was determined from the F-Snedecor tables $F_{?,s1,s2,}$? = 0.05

$s_1 = 1$, $s_2 = n-2 = 28-2 = 26$

$F_{0.05,1.26} = 4.23$

The result of the test F = 21.319 falls within the designated critical area, so we reject H_0 in favor of H_1. This means that the value of pull-off tensile strength in dry conditions significantly depends on the density of thermal insulation at the level of significance 0.05.

Determine the relationship (regression) between the pull-off strength of the C2S1 adhesive and the type of thermal insulation EPS and XPS only in wet conditions.

In order to check the relationship between the tested pull-off tensile strength only in wet conditions of the lightweight floor system, and the type of thermal insulation EPS200 and XPS300, the method of mass phenomena in the form of linear regression was used. A single method of least squares was used. An evacuated (loaded) variable is the tensile strength and the explanatory (weighting) density of thermal insulation. The pull-off strength data from the tests and the minimum density of materials used with a value of 28 kg/m[3] in EPS and 34 kg/ m[3] in XPS are shown in Table 4. The estimation of the Y regression function with respect to X in the general population is the regression function y versus x in the random sample having the following form:

$\hat{y} = a_y\ x + b_y$

Where

$$a_y = \frac{n\Sigma x_j y_j - \Sigma x_j \Sigma y_j}{n\Sigma x_j^2 - (\Sigma x_j)^2}, b_y = \overline{y_j} - a_y \overline{x_j}$$

$$a_y = \frac{20\times 132.288 - 620\times 4.248}{20\times 19400-(620)^2} = 0.00333 \approx 0.0033$$

$$b_y = 0.2124 - 0.0033\times 31 = 0.1101$$

From this conclusion, the increase in the density of thermal insulation by 1 kg/m[3] increases the pull-off tensile strength in wet conditions by 0.0033 MPa. This means that the pull-of method in wet conditions is higher when we apply the XPS 300 insulation against EPS 200 by 0.02 MPa, bearing in mind the adopted density of these materials.

Verification of hypotheses regarding the relationship (regression) between the pull-off strength of the C2S1 adhesive, and the type of thermal insulation EPS and XPS only in wet conditions.

In order to determine whether there is a significant relationship between the analyzed variables (wet pull-off strength and thermal insulation density), the hypothesis of complete lack of regression of y/x should be verified. The hypothesis of the complete absence of regression - F test, i.e. pull-off strength and thermal insulation density:

H_0: no regression; H_1: regression exists - right-handed

The F-Snedecor test was used for this purpose.

$$F = \frac{MSR}{MSE}, \text{ Where } SR = SSR, SSR = \frac{\left(\Sigma x_j y_j - \frac{\Sigma x_j y_j}{n}\right)^2}{\Sigma x_j^2 - \frac{(\Sigma x_j)^2}{n}}, MSE = \frac{SSE}{n-2}, SSE = SST - SSR$$

$$SST = \Sigma y_j^2 - \frac{(\Sigma y_j)^2}{n} = 0.920864 - \frac{(4.248)^2}{20} = 0.01859$$

$$SSR = \frac{\left(132.288 - \frac{4.248\times 620}{20}\right)^2}{19400 - \frac{(620)^2}{20}} = 0.002$$

SSE = 0.01859 – 0.002 = 0.01659

$$MSE = \frac{0.01659}{18} = 0.0009216$$

$$F = \frac{0.002}{0.0009216} = 2.17$$

The right-handed critical area was determined from the F-Snedecor tables $F_{\alpha,s1,s2,}$ $\alpha = 0.05$

$s_1 = 1$, $s_2 = n-2 = 20-2 = 18$

$F_{0.05,1.18} = 4.41$

The result of the test F = 2.17 does not fit in the designated critical area, therefore we accept the hypothesis of no dependence of H_0. This means that the value of pull-off method in wet conditions does not depend significantly on the density of thermal insulation at the significance level of 0.05.

Conclusion

Conducted statistical analysis, consisting in the verification of hypotheses, assessment of the strength of connections, and checking the relationship between pull-off strength of the C2S1 type adhesive in dry, wet and mixed conditions, which combine ceramic tiles of two types of EPS 200 or XPS 300 insulation substrate, showed that:

a) The value of pull-off tensile strength in dry and mixed conditions significantly depends on the density of thermal insulation, and in wet conditions does not depend significantly on it, with a significance level of 0.05.

b) An increase in the density of thermal insulation by 1 kg/m^3 results in an increase pull-off strength of the deformable cement adhesive C2S1 type in various test conditions. Using thermal insulation of XPS 300 relative to EPS 200, where the difference between the density of these materials is 6 kg/m^3, the pull-off strength of the deformable adhesive C2S1 type on the XPS insulation relative to the EPS will be higher by:

i. 0.04 MPa in mixed conditions

ii. 0.06 MPa in dry conditions

iii. 0.02 MPa in wet conditions

c) At 95% certainty, we can not assume that there is a statisticaly significant relationship between the average tensile strength of the adhesive and the EPS or XPS insulation substrate, tested in dry and wet conditions. Confirmation of the lack of correlation of the studied variables is the value of Czuprowa T_{xy} <0.2.

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