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REPORT No. Z - 18 - 018

VALIDATION OF METHODOLOGY FOR DETERMINATION OF SHEAR BEHAVIOUR CHARACTERISTICS OF THERMAL INSULATION MATERIALS IN ACCORDANCE WITH EN 12090 FOR THICKNESS OF SAMPLES HIGHER THAN 50 mm AND DETERMINATION OF REFERENCE RELATION

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1. REPORT SUBJECT

Subject of report is solving of project classed to Program of development of testing for year 2018 - Validation of methodology for determination of shear behaviour characteristics of thermal insulation materials in accordance with ČSN EN 12090 for thickness of samples higher than 50 mm and determination of reference relation. Final version is after settlements of suggestions and comments of opponents.

Project was solved on basis of contract No. 18/1.5/VUPS of 19th April 2018.

2. TASK AND SPECIFICATION OF PROJECT

- Determination of shear strength and shear modulus in accordance with ČSN EN 12090 by double test specimen for samples with different thickness of test samples.
- Performance of tests with two most usual thermal insulation products used on ETICS – expanded polystyrene and mineral wool with thickness of samples:

  50 mm; 80 mm; 100 mm; 120 mm; 140 mm.
- This task was during solving of project was changed by settlement to thicknesses (50; 100; 120; 160 a 200) mm , which better corresponding with thicknesses of boards which are actually used for ETICS.

For verification of homogeneity of sample unit will be tested:

- determination of apparent density of whole boards and test specimen in according with ČSN EN 1602
- determination of compression behaviour in accordance with ČSN EN 826 for EPS samples
- determination of tensile strength perpendicular to faces in accordance with ČSN EN 1607 for mineral wool samples.

Apparent density will be determined for all test specimen and all board used for sampling of each specimen.

Determination of compression behaviour and tensile strength perpendicular to faces will be performed on 3 test samples for each sample material and each thickness.

Totally will be performed:

- 100 determination of shear behaviour and shear modulus
- 15 determination of compression behaviour
- 15 determination of tensile strength perpendicular to faces
- 200 determination of apparent density of specimen
- approx. 20 determination of apparent density for whole boards (related to sampling)

Result of project will be: Report „Validation of methodology for determination of shear behaviour characteristics of thermal insulation materials in accordance with ČSN EN 12090 for thickness of samples higher than 50 mm and determination of reference relation.“

3. OBJECTIVE NEED OF SOLVING THE PROJECT

Standard ČSN EN 12090:2013 „Thermal insulating products for building applications - Determination of shear behaviour“, Clause 4, note posted that double test specimen method indicate influence of specimen thickness to shear behaviour results. Influence of thickness to shear behaviour characteristics is not specified in cited standard and also product standards, for example ČSN EN 13162 (MW), ČSN EN 13163 (EPS) and so on.

Testing is performed on test samples as is specified in product standards. If is not specified, standards for testing are used. For testing shear characteristics of EPS are specimen dimensions 50 mm x 250 mm x.th. 50 mm – max. MW testing is performed on specimen with dimensions 250 mm x 100 mm x th. of product without upper limit, for example 250

mm x 100 mm x 200 mm. For both cases is clear that test result will not corresponding with product characteristics. For EPS boards is not presupposed relation shear characteristics to thickness and in case of MW boards is thickness of specimen for samples with higher thickness is thickness equal or higher than specimen area and it is not sample when thickness should be much less than area dimensions. Experiences verifying, that for higher thicknesses of specimen for double specimen method are specimen loaded by combination of shear/ tensile strength/ compression. Is clear, that designed values of shear characteristics of EPS and MW derived of test results for design and assessment of ETICS are not corresponding with characteristics of products from which are ETICS performed. Reason of urgency of project solving is, that thermal insulation boards for ETICS are efficient and transfer outer permanent and random load to base. Actually is not exceptional ETICS with 200 mm thickness.

4. PERFORMANCE OF TESTS

Test were performed by certified Testing laboratory No. 1234 of contractor of research in accordance with related standards cited in report.

5. SAMPLING, TAKING AND MARKING OF TEST SAMPLES

Sampling of expanded polystyrene boards units in accordance with ČSN EN 13163 (marked EPS) and mineral wool boards units in accordance with ČSN EN 13 162 (marked MW) was performed by sampling from market. Sampled units were bought by one seller in one random batch from warehouse of seller.

Units of EPS and MW boards were sampled in packages without defects. Sampled units and unit´s marking is posted in following table.

Table 1. Marking of boards units and types of thermal insulation

No. of unit	Type of isolation – thickness	Quantity of boards in unit	Quantity of units
245/18	MW TR10 – 50 mm	4	1
246/18	MW TR10 – 100 mm	2	2
247/18	MW TR10 – 120 mm	2	2
248/18	MW TR10 – 160 mm	2	2
249/18	MW TR10 – 200 mm	1	3
250/18	EPS 70 – 50 mm	10	1
251/18	EPS 70 – 100 mm	5	1
252/18	EPS 70 – 120 mm	4	2
253/18	EPS 70 – 160 mm	3	2
254/18	EPS 70 – 200 mm	2	2

MW boards units were by one manufacturer only with different thickness (identical trade name and identical declaration of tensile strength TR 10 class. EPS boards units were by two

manufacturers and with different thickness (identical declaration of tensile strength TR 10) class), one manufacturer has no whole range of thicknesses.

From sampled units were randomly chosen 2 boards, which were used for sampling of test samples and for testing. That boards were marked by using caps letters (/A, /B, /C…). Test samples sampled from boards were marked by following numbers after letters (/1, /2,…).

If it was possible, margin boards were excluded, because of possibility of defects by manipulations, storing and transporting of units to testing laboratory. Test specimen, were sampled from boards as is shown on Figure 1.

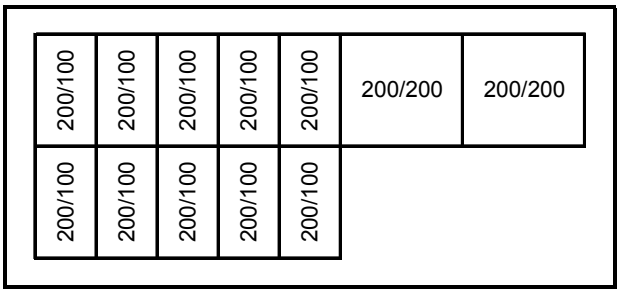


Figure 1 Sampling of specimen from board

Each specimen were prepared by cutting with band saw, all time was keep minimal distance 50 mm from board edge.

For determination of shear characteristics were prepared specimen with dimensions 200 mm/100 mm/ thickness of board. Specimen with dimensions 200 mm/200 mm were used for determination of compressive behaviour and tensile strength perpendicular to faces.

For determination of shear characteristics by using double test specimen method were specimen paired to be every time used specimen from the same area of board in direction of width (longer edge).

For fixing specimen to steel boards for shear behaviour testing was used PUR foam intended for ETICS.

Figures of test samples with EPS and MW specimen are posted in Annex of this report.

6. MEASURED VALUES AND TEST RESULTS

6.1 Determination of apparent density of MW a EPS boards

The test was performed in accordance with ČSN EN 1602: 2013 - Thermal insulating products for building applications - Determination of the apparent density.

Boundary conditions of the test were in compliance with ČSN EN 13162+A1:2016 a ČSN EN 13163+A2:2017.

The test samples were stored at laboratory conditions and ambient temperature (22 ± 2) °C and (55 ± 5) % R.H. during at least 7 days.

Determination was performed only for boards used for sampling of specimen.

In accordance with ČSN EN 1602:2016 are area dimensions and thickness are stated to closest millimetre, mass with accuracy 0.5 % (0.01 kg for mineral wool and 0.001 kg for EPS) and apparent density was calculated from rounded values and is stated in 3 significant figures.

For purpose determination is not stated average value of test.

6.1.1 MW boards

Following table (Table 2) stated measured values for determination of apparent density by laboratory humidity and test result of apparent density of MW boards.

Table 2. Measured values and apparent density of **MW boards** in laboratory humidity

Board no.	Length l [mm]	Width b [mm]	Thickness of MW boards				Mass m [kg]	Apparent density ρ_a [kg/m^3]
			d_1 [mm]	d_2 [mm]	d_3 [mm]	d_4 [mm]		
245/18 B	600	1000	49	49	49	49	3.62	**123.0**
245/18 C	601	1000	49	50	50	50	3.59	**120.0**
246/18 A	599	998	100	100	100	100	5.87	**98.2**
246/18 B	599	998	100	100	100	100	5.91	**98.9**
247/18 B	600	1000	120	120	120	120	7.02	**97.5**
247/18 C	600	1000	122	121	121	120	6.95	**95.7**
248/18 B	601	1002	161	160	162	161	9.19	**94.8**
248/18 C	601	1003	161	160	161	161	9.25	**95.5**
249/18 B	600	1002	201	201	201	201	11.95	**98.9**
249/18 C	600	1002	201	201	201	200	11.68	**96.8**

6.1.2 EPS boards

Following table (Table 3) stated measured values for determination of apparent density by laboratory humidity and test result of apparent density of EPS boards.

Table 3. Measured values and apparent density of **EPS boards** in laboratory

Board no.	Length l [mm]	Width b [mm]	Thickness of EPS boards				Mass m [kg]	Apparent density ρ_a [kg/m^3]
			d_1 [mm]	d_2 [mm]	d_3 [mm]	d_4 [mm]		
250/18 E	498	998	50	50	50	51	0.310	**12.4**
250/18 F	499	998	50	50	50	51	0.310	**12.4**
251/18 B	501	1000	100	100	100	100	0.684	**13.7**
251/18 C	502	1000	101	100	101	101	0.671	**13.3**
252/18 B	501	1000	121	121	120	120	0.791	**13.1**
252/18 F	501	1000	121	120	120	121	0.823	**13.6**
253/18 B	500	1001	162	162	161	162	1.008	**12.5**
253/18 E	500	1001	162	161	162	162	1.043	**12.9**
254/18 B	500	1000	201	201	201	201	1.227	**12.2**
254/18 D	500	1001	201	201	201	201	1.187	**11.8**

6.2 Determination of compressive behaviour for EPS

Identification test was performed in accordance with ČSN EN 826:2013 Thermal insulating products for building applications - Determination of compression behaviour.

Boundary conditions of the test were in compliance with ČSN EN 13163+A2:2017.

The test samples were stored at laboratory conditions and ambient temperature (22 ± 2) °C and (55 ± 5) % R.H. during at least 7 days.

Test was performed on specimen with dimensions 200 mm × 200 mm × thickness of product.

In accordance with ČSN EN 1602:2016 is apparent density stated on 3 significant figures and in accordance with ČSN EN 826 is compressive behaviour by 10% compression.

Measured values and test results are in following tables sorted by board thickness.

Table 4. Compressive behaviour by 10% compression, **EPS, th. 50 mm**

Sample no.	Apparent density of specimen [kg/m^3]	Compressive behaviour by 10% compression [kPa]
250/18 E1	12.9	62.1
250/18 E2	12.4	59.8
250/18 F1	12.3	59.8
Test result – average value		**60.6 kPa**

Table 5. Compressive behaviour by 10% compression, **EPS, th. 100 mm**

Sample no.	Apparent density of specimen [kg/m^3]	Compressive behaviour by 10% compression [kPa]
251/18 B1	13.6	69.0
251/18 B2	13.2	66.9
251/18 C1	13.2	71.0
251/18 C2	13.0	65.7
Test result – average value		**68.2 kPa**

Table 6. Compressive behaviour by 10% compression, **EPS, th. 120 mm**

Sample no.	Apparent density of specimen [kg/m^3]	Compressive behaviour by 10% compression [kPa]
252/18 B1	12.9	61.2
252/18 B2	12.8	65.4
252/18 C1	14.2	75.3
252/18 C2	13.6	72.1
Test result – average value		**70.9 kPa**

Table 7. Compressive behaviour by 10% compression, **EPS, th. 160 mm**

Sample no.	Apparent density of specimen [kg/m^3]	Compressive behaviour by 10% compression [kPa]
253/18 B1	12.5	64.1
253/18 B2	12.4	65.4
253/18 E1	13.3	69.1
253/18 E2	12.7	66.9
Test result – average value		**66.4 kPa**

Table 8. Compressive behaviour by 10% compression, **EPS, th. 200 mm**

Sample no.	Apparent density of specimen [kg/m^3]	Compressive behaviour by 10% compression [kPa]
254/18 B1	12.3	61.0
254/18 B2	12.2	61.1
254/18 D1	11.8	59.4
254/18 D2	12.0	62.2
Test result – average value		**60.9 kPa**

6.3 Determination of tensile strength perpendicular to faces for MW

Identification test was performed in accordance with ČSN EN 1607: 2013 - Thermal insulating products for building applications - Determination of tensile strength perpendicular to faces.

Boundary conditions in accordance with ČSN EN 13162+A1:2016 and ČSN EN 13163+A1:2016.

The test samples were stored at laboratory conditions and ambient temperature (22 ± 2) °C and (55 ± 5) % R.H. at least 7 days.
Dimensions of specimens 200 mm × 200 mm × thickness of specimen.

Measured values and test results of determination of tensile strength perpendicular to faces are stated in following tables sorted by boards thickness.

Table 9. Tensile strength perpendicular to faces, **MW 50 mm**

Sample no.	Apparent density of specimen ρ_a [kg/m^3]	Tensile strength perpendicular to faces σ_{mt} [kPa]
245/18 B1	124	14.5
245/18 B2	122	10.3
245/18 C1	121	17.1
245/18 C2	120	15.0
Test result – average tensile strength perpendicular to faces		**14 kPa**

Table 10. Tensile strength perpendicular to faces, **MW 100 mm**

Sample no.	Apparent density of specimen ρ_a [kg/m^3]	Tensile strength perpendicular to faces σ_{mt} [kPa]
246/18 A1	98.8	10.1
246/18 A2	98.6	8.6
246/18 B1	95.6	9.1
246/18 B2	97.0	6.9
Test result – average tensile strength perpendicular to faces		**8.7 kPa**

Table 11. Tensile strength perpendicular to faces, **MW 120 mm**

Sample no.	Apparent density of specimen ρ_a [kg/m^3]	Tensile strength perpendicular to faces σ_{mt} [kPa]
247/18 B1	97.5	7.8
247/18 B2	97.9	7.4
247/18 C1	93.0	5.9
247/18 C2	97.9	3.9
Test result – average tensile strength perpendicular to faces		**6.2 kPa**

Table 12. Tensile strength perpendicular to faces, **MW 160 mm**

Sample no.	Apparent density of specimen ρ_a [kg/m^3]	Tensile strength perpendicular to faces σ_{mt} [kPa]
248/18 B1	95.5	13.7
248/18 B2	95.1	13.2
248/18 C1	92.2	12.7
248/18 C2	94.6	13.2
Test result – average tensile strength perpendicular to faces		**13 kPa**

Table 13. Tensile strength perpendicular to faces, **MW 200 mm**

Sample no.	Apparent density of specimen ρ_a [kg/m^3]	Tensile strength perpendicular to faces σ_{mt} [kPa]
249/18 B1	99.2	15.2
249/18 B2	97.5	17.6
249/18 C1	95.8	11.3
249/18 C2	95.6	11.8
Test result – average tensile strength perpendicular to faces		**14 kPa**

6.4 Determination of shear behaviour and shear modulus

The test was performed in accordance with ČSN EN 12090: 2013 - Thermal insulating products for building applications - Determination of shear behaviour.

Boundary conditions in accordance with ČSN EN 13162+A1:2016 and ČSN EN 13163+A1:2016.

The test samples were stored at laboratory conditions and ambient temperature (22 ± 2) °C and (55 ± 5) % R.H. at least 7 days.

Test was performed by double test specimen method with two specimens with dimensions (200 x 100) mm / thickness of specimen equal to board thickness. Specimen, were prepared to keep orientation length and width in relation to load in testing apparatus.

Standard ČSN EN 13162 (MW) determine in Clause 5.3 *Testing* in *Table 5 - Test methods, test specimens and condition* that specimen for double test method has dimensions (200 x 100) mm with that dimensions of specimen product standard does not change and is valid Clause 6.3 of ČSN EN 12090 and thickness of specimen is equal to thickness of product. Dimension of each part of test sample are normative 200 mm x 100 mm x thickness of product; for the project in range 50 mm - 200 mm.

Note: For single test specimen – Sub Clause 6.1.2 ČSN EN 12090 is normative dimension 250 mm x 50 mm.

Standard ČSN EN 13163 (EPS) determine in Clause 5.3 *Testing* in *Table 9 - Test methods, test specimens and condition* that specimen for double test method has dimensions (50 x 250) mm with that thickness of specimen is in Note h) is limited by 50 mm thickness. Test specimen dimension should be 50 mm x 250 mm x thickness 50 mm for all thicknesses of EPS boards.

Note: For single specimen standard ČSN EN 13163 define dimension 250 mm x 50 mm. For EPS are dimensions for both method identical!

Determination of shear behaviour and calculated shear modulus was performed with specimen 200 mm x 100 mm x thickness of product for MW and also EPS to be possible comparison of results and movement of relations

Results of all determinations are stated in following tables.

6.4.1 Mineral wool - MW

Test results of determination of shear behaviour and calculated shear modulus of MW is stated in following tables, sorted by thickness of products.

Table 14. Test results of determination of shear behaviour and shear modulus, **MW 50 mm**

Sample no.	Apparent density of specimen ρ_a [kg/m^3]	Shear behaviour σ [kPa]	Shear modulus G [kPa]
245/18 B12	120	29	830
	122		
245/18 B34	126	29	920
	124		
245/18 B56	125	28	870
	123		
245/18 B78	130	35	1030
	121		
245/18 B910	127	32	980
	120		
245/18 C12	115	34	970
	118		
245/18 C34	120	35	1040
	118		
245/18 C56	121	28	940
	122		
245/18 C78	117	31	910
	118		
245/18 C910	122	32	990
	114		
Test result – average value		**31 kPa**	**948 kPa**

Table 15. Test results of determination of shear behaviour and shear modulus, **MW 100 mm**

Sample no.	Apparent density of specimen ρ_a [kg/m^3]	Shear behaviour σ [kPa]	Shear modulus G [kPa]
246/18 A12	98.0	16	600
	98.8		
246/18 A34	94.8	17	630
	95.7		
246/18 A56	100	16	580
	101		
246/18 A78	97.7	16	570
	102		
246/18 A910	100	16	610
	98.8		
246/18 B12	94.2	16	590
	96.6		
246/18 B34	94.3	16	590
	94.7		
246/18 B56	96.1	15	530
	97.0		
246/18 B78	98.1	15	470
	98.5		
246/18 B910	132	19	760
	99.5		
Test result – average value		**16 kPa**	**593 kPa**

Test results of determination of shear behaviour and shear modulus, **MW 120 mm**

Sample no.	Apparent density of specimen ρ_a [kg/m^3]	Shear behaviour σ [kPa]	Shear modulus G [kPa]
247/18 B1+2	96.7	10	290
	97.1		
247/18 B3+4	95.6	15	320
	94.8		
247/18 B5+6	97.1	15	490
	100		
247/18 B7+8	98.0	14	530
	98.5		
247/18 B9+10	96.3	16	360
	95.9		
247/18 C1+2	102	8	230
	98.6		
247/18 C3+4	95.0	9	210
	97.8		
247/18 C5+6	89.1	7	230
	94.2		
247/18 C7+8	88.2	8	220
	91.8		
247/18 C9+10	97.0	10	270
	96.9		
Test result – average value		**11 kPa**	**315 kPa**

Table 16. Test results of determination of shear behaviour and shear modulus, **MW 160 mm**

Sample no.	Apparent density of specimen ρ_a [kg/m^3]	Shear behaviour σ [kPa]	Shear modulus G [kPa]
248/18 B12	98.8	13	640
	96.3		
248/18 B34	96.2	12	580
	92.5		
248/18 B56	97.4	13	630
	94.0		
248/18 B78	95.9	12	500
	89.9		
248/18 B910	96.1	11	400
	90.3		
248/18 C12	94.4	12	490
	95.9		
248/18 C34	96.4	14	700
	95.2		
248/18 C56	94.0	13	540
	93.5		
248/18 C78	95.8	14	300
	93.1		
248/18 C910	94.4	13	390
	94.9		
Test result – average value		**13 kPa**	**517 kPa**

Table 17. Test results of determination of shear behaviour and shear modulus, **MW 200 mm**

Sample no.	Apparent density of specimen ρ_a [kg/m^3]	Shear behaviour σ [kPa]	Shear modulus G [kPa]
249/18 B12	101	12	470
	96.2		
249/18 B34	98.0	10	270
	95.6		
249/18 B56	101	10	410
	98.6		
249/18 B78	98.6	10	410
	98.3		
249/18 B910	97.5	9,0	340
	100		
249/18 C12	95.2	9,4	360
	98.0		
249/18 C34	95.8	9,9	460
	96.2		
249/18 C56	95.7	11	490
	95.8		
249/18 C78	98.9	10	430
	99.2		
249/18 C910	96.0	10	280
	96.4		
Test result – average value		**10 kPa**	**392 kPa**

6.4.2 Expanded polystyrene – EPS

Test results of determination of shear behaviour and calculated shear modulus of EPS is stated in following tables, sorted by thickness of products.

Table 18. Test results of determination of shear behaviour and shear modulus, **EPS 50 mm**

Sample no.	Apparent density of specimen ρ_a [kg/m^3]	Shear behaviour σ [kPa]	Shear modulus G [kPa]
250-18 E12	11.9	65	1400
	12.1		
250-18 E34	11.9	57	1100
	13.3		
250-18 E56	12.3	58	1100
	12.3		
250-18 E78	12.4	56	1000
	12.4		
250-18 E910	12.6	take out, defect in glue	
	12.5		
250-18 F12	12.1	61	1200
	11.8		
250-18 F34	12.0	59	1000
	11.9		
250-18 F56	12.1	55	1200
	12.2		
250-18 F78	12.2	55	1100
	12.3		
250-18 F910	12.4	55	1100
	12.4		
Test result – average value		**58 kPa**	**1133 kPa**

Table 19. Test results of determination of shear behaviour and shear modulus, **EPS 100 mm**

Sample no.	Apparent density of specimen ρ_a [kg/m^3]	Shear behaviour σ [kPa]	Shear modulus G [kPa]
251/18 B12	13.4	43	1400
	13.6		
251/18 B34	13.5	42	1400
	13.6		
251/18 B56	13.4	44	1300
	13.7		
251/18 B78	13.6	43	1400
	13.9		
251/18 B910	13.9	41	1400
	13.6		
251/18 C12	12.8	44	1300
	12.9		
251/18 C34	12.9	40	1200
	13.0		
251/18 C56	12.9	37	1200
	12.9		
251/18 C78	12.9	39	1400
	13.1		
251/18 C910	13.2	41	1200
	13.1		
Test result – average value		**41 kPa**	**1320 kPa**

Table 20. Test results of determination of shear behaviour and shear modulus, **EPS 120 mm**

Sample no.	Apparent density of specimen ρ_a [kg/m^3]	Shear behaviour σ [kPa]	Shear modulus G [kPa]
252-18 B12	12.9	44	1100
	13.0		
252-18 B34	13.0	44	1200
	13.0		
252-18 B56	13.2	44	1300
	13.2		
252-18 B78	13.3	25	1200
	13.6		
252-18 B910	13.2	44	1300
	13.2		
252-18 F12	13.0	43	1300
	13.1		
252-18 F34	13.2	46	1300
	13.2		
252-18 F56	13.3	46	1400
	13.2		
252-18 F78	13.4	46	1400
	13.3		
252-18 F910	13.7	45	1300
	13.7		
Test result – average value		**43 kPa**	**1280 kPa**

Table 21. Test results of determination of shear behaviour and shear modulus, **EPS 160 mm**

Sample no.	Apparent density of specimen ρ_a [kg/m^3]	Shear behaviour σ [kPa]	Shear modulus G [kPa]
253-18 B12	12.4	36	1100
	12.4		
253-18 B34	12.9	35	1100
	12.6		
253-18 B56	12.6	35	1100
	12.5		
253-18 B78	12.4	34	1000
	12.5		
253-18 B910	12.4	33	1100
	12.4		
253-18 E12	12.9	37	1100
	13.3		
253-18 E34	12.9	36	1100
	12.9		
253-18 E56	13.2	35	1100
	13.0		
253-18 E78	13.0	33	1200
	12.9		
253-18 E910	13.1	33	1200
	13.0		
Test result – average value		**35 kPa**	**1100 kPa**

Table 22. Test results of determination of shear behaviour and shear modulus, **EPS 200 mm**

Sample no.	Apparent density of specimen ρ_a [kg/m^3]	Shear behaviour σ [kPa]	Shear modulus G [kPa]
254-18 B12	12.2	23	850
	12.2		
254-18 B34	12.0	22	810
	12.1		
254-18 B56	12.2	20	890
	12.3		
254-18 B78	12.2	19	800
	12.1		
254-18 B910	12.0	20	840
	11.9		
254-18 D12	11.9	28	910
	12.0		
254-18 D34	12.0	23	840
	11.9		
254-18 D56	11.9	23	900
	11.8		
254-18 D78	11.8	24	850
	11.9		
254-18 D910	11.9	22	890
	12.1		
Test result – average value		**22 kPa**	**858 kPa**

7. STATISTIC ASSESMENT OF TEST RESULTS

Base of statistics analysis was critical assessment of test results and finding outlying values.

This assessment was performed by using parametric one-sample Grubbs test for each measured thickness of EPS and MW. Premise for performing of this test is normal distribution of test results. For needs of this analysis were taken out from assessment all outlying values – all results for which was testing statistic equal or higher than 5% critical value for given count of results *n*.

Results of Grubbs test for outlying values for MW, sorted by thickness, are stated in following tables.

Table 23. Shear behaviour **MW 50 mm** - results of Grubbs test

Characteristic	Value for n=10
Maximal value	35
Minimal value	28
Average value	31
Standard deviation	2.6
Grubbs statistics (maximal value)	1.265
Grubbs statistics (minimal value)	1.418
5% critical value	**2.294**
Result: No outlying value	

Table 24. Shear modulus **MW 50 mm** - results of Grubbs test

Characteristic	Value for n=10
Maximal value	1040
Minimal value	830
Average value	948
Standard deviation	63.8
Grubbs statistics (maximal value)	1.838
Grubbs statistics (minimal value)	1.441
5% critical value	2.294
Result: No outlying value	

Table 25. Shear behaviour **MW 100 mm** - results of Grubbs test

Characteristic	Value for n=10
Maximal value	19
Minimal value	15
Average value	16
Standard deviation	1.1
Grubbs statistics (maximal value)	0.965
Grubbs statistics (minimal value)	2.600
5% critical value	2.294
Result: outlying maximal value (246/18 B910). Testing after taking out outlying value no another else outlying value.	

Table 26. Shear modulus **MW 100 mm** - results of Grubbs test

Characteristic	Value for n=10
Maximal value	760
Minimal value	470
Average value	593
Standard deviation	70.3
Grubbs statistics (maximal value)	1.521
Grubbs statistics (minimal value)	2.376
5% critical value	2.294
Result: outlying maximal value (246/18 B910) minimal value 246/18 B78. Testing after taking out outlying value no another else outlying value.	

Table 27. Shear behaviour **MW 120 mm** - results of Grubbs test

Characteristic	Value for n=10
Maximal value	16
Minimal value	7
Average value	11
Standard deviation	3.3
Grubbs statistics (maximal value)	1.131
Grubbs statistics (minimal value)	1.475
5% critical value	2.294
Result: No outlying value	

Table 28. Shear modulus **MW 120 mm** - results of Grubbs test

Characteristic	Value for n=10
Maximal value	530
Minimal value	210
Average value	315
Standard deviation	107.7
Grubbs statistics (maximal value)	0.895
Grubbs statistics (minimal value)	1.996
5% critical value	2.294
Result: No outlying value	

Table 29. Shear behaviour **MW 160 mm** - results of Grubbs test

Characteristic	Value for n=10
Maximal value	14
Minimal value	11
Average value	13
Standard deviation	0.9
Grubbs statistics (maximal value)	1.807
Grubbs statistics (minimal value)	1.444
5% critical value	2.294
Result: No outlying value	

Table 30. Shear modulus **MW 160 mm** - results of Grubbs test

Characteristic	Value for n=10
Maximal value	700
Minimal value	300
Average value	517
Standard deviation	119.9
Grubbs statistics (maximal value)	1.579
Grubbs statistics (minimal value)	1.526
5% critical value	2.294
Result: No outlying value	

Table 31. Shear behaviour **MW 200 mm** - results of Grubbs test

Characteristic	Value for n=10
Maximal value	12
Minimal value	9
Average value	10
Standard deviation	0.8
Grubbs statistics (maximal value)	1.709
Grubbs statistics (minimal value)	2.373
5% critical value	2.294
Result: outlying maximal value (249/18 B12). Testing after taking out outlying value no another else outlying value.	

Table 32. Shear modulus **MW 200 mm** - results of Grubbs test

Characteristic	Value for n=10
Maximal value	490
Minimal value	270
Average value	392
Standard deviation	73.2
Grubbs statistics (maximal value)	1.848
Grubbs statistics (minimal value)	1.339
5% critical value	2.294
Result: No outlying value	

Results of Grubbs test for outlying values for EPS, sorted by thickness, are stated in following tables.

Table 33. Shear behaviour **EPS 50 mm** - results of Grubbs test

Characteristic	Value for n=9
Maximal value	65
Minimal value	55
Average value	58
Standard deviation	3.2
Grubbs statistics (maximal value)	0.907
Grubbs statistics (minimal value)	2.238
5% critical value	2.237
Result: outlying maximal value (250/18 E12). Testing after taking out outlying value no another else outlying value.	

Table 34. Shear modulus **EPS 50 mm** - results of Grubbs test

Characteristic	Value for n=9
Maximal value	1400
Minimal value	1000
Average value	1133
Standard deviation	115.5
Grubbs statistics (maximal value)	1.323
Grubbs statistics (minimal value)	2309
5% critical value	2.237
Result: outlying maximal value (250/18 E12). Testing after taking out outlying value no another else outlying value.	

Table 35. Shear behaviour **EPS 100 mm** - results of Grubbs test

Characteristic	Value for n=10
Maximal value	44
Minimal value	37
Average value	41
Standard deviation	2.2
Grubbs statistics (maximal value)	1.782
Grubbs statistics (minimal value)	1.207
5% critical value	2.294
Result: No outlying value	

Table 36. Shear modulus **EPS 100 mm** - results of Grubbs test

Characteristic	Value for n=10
Maximal value	1400
Minimal value	1200
Average value	1320
Standard deviation	87.2
Grubbs statistics (maximal value)	1.155
Grubbs statistics (minimal value)	0.918
5% critical value	2.294
Result: No outlying value	

Table 37. Shear behaviour **EPS 120 mm** - results of Grubbs test

Characteristic	Value for n=10
Maximal value	46
Minimal value	25
Average value	43
Standard deviation	6.0
Grubbs statistics (maximal value)	2.612
Grubbs statistics (minimal value)	0.551
5% critical value	2.294
Result: outlying minimal value (252/18 78). Testing after taking out outlying value no another else outlying value.	

Table 38. Shear modulus **EPS 120 mm** - results of Grubbs test

Characteristic	Value for n=10
Maximal value	1400
Minimal value	1100
Average value	1280
Standard deviation	87.2
Grubbs statistics (maximal value)	1.877
Grubbs statistics (minimal value)	1.376
5% critical value	2.294
Result: No outlying value	

Table 39. Shear behaviour **EPS 160 mm** - results of Grubbs test

Characteristic	Value for n=10
Maximal value	37
Minimal value	33
Average value	35
Standard deviation	1.3
Grubbs statistics (maximal value)	1.061
Grubbs statistics (minimal value)	1.710
5% critical value	2.294
Result: No outlying value	

Table 40. Shear modulus **EPS 160 mm** - results of Grubbs test

Characteristic	Value for n=10
Maximal value	1200
Minimal value	1000
Average value	1110
Standard deviation	53.9
Grubbs statistics (maximal value)	1.877
Grubbs statistics (minimal value)	1.671
5% critical value	2.294
Result: No outlying value	

Table 41. Shear behaviour **EPS 200 mm** - results of Grubbs test

Characteristic	Value for n=10
Maximal value	28
Minimal value	19
Average value	22
Standard deviation	2.4
Grubbs statistics (maximal value)	1.255
Grubbs statistics (minimal value)	2.317
5% critical value	2.294
Result: outlying maximal value (254/18 D12). Testing after taking out outlying value no another else outlying value.	

Table 42. Shear modulus **EPS 200 mm** - results of Grubbs test

Characteristic	Value for n=10
Maximal value	910
Minimal value	800
Average value	858
Standard deviation	36.0
Grubbs statistics (maximal value)	1.820
Grubbs statistics (minimal value)	1.444
5% critical value	2.294
Result: No outlying value	

Numeric assessment of measured values by Grubbs test indicated exceeding of measured values for this test samples:

- MW -100mm 246/18 B910 – shear behaviour, shear modulus
- MW -100mm 246/18 B78 – shear modulus
- MW - 200 mm 249/18 B12 – shear behaviour
- EPS - 50 mm 250/18 E12 – shear behaviour, shear modulus
- EPS - 120 mm 252/18 B78 – shear behaviour
- EPS - 200 mm 254/18 D12 – shear behaviour

8. REGRESSION ANALYSIS OF TEST RESULTS

After taking out outlying data from data collection was determined average value of observed characteristics for different thicknesses. These data were used for regression analysis, determination of regression dependence values of shear behaviour and shear modulus in dependence on thickness of test samples.

Regression analysis was performed by using MS Excel. Was chosen type of dependence with maximal value R^2, so with highest closeness test results to regression dependence in accordance with real physical dependence of correlated volumes.

Is possible to say, that trend of dependence shear behaviour and shear modulus will be purely monotinu, without turnaround and saddle. It was criterion for choice type of regression function.

Table 43. Test results of shear behaviour and shear modulus as average values of non-outlying results - **MW**

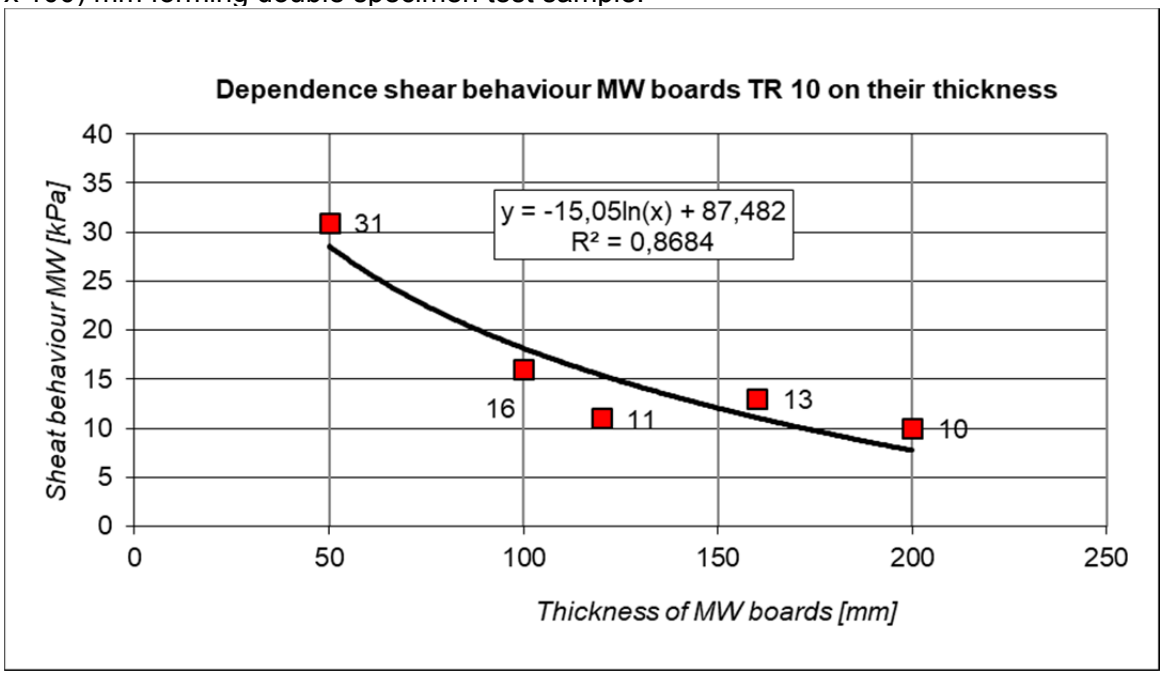
Nominal thickness [mm]	Shear behaviour [kPa]	Shear modulus [kPa]
50	31	948
100	16	588
120	11	315
160	13	517
200	10	392

Table 44. Test results of shear behaviour and shear modulus as average values of non-outlying results – **EPS**

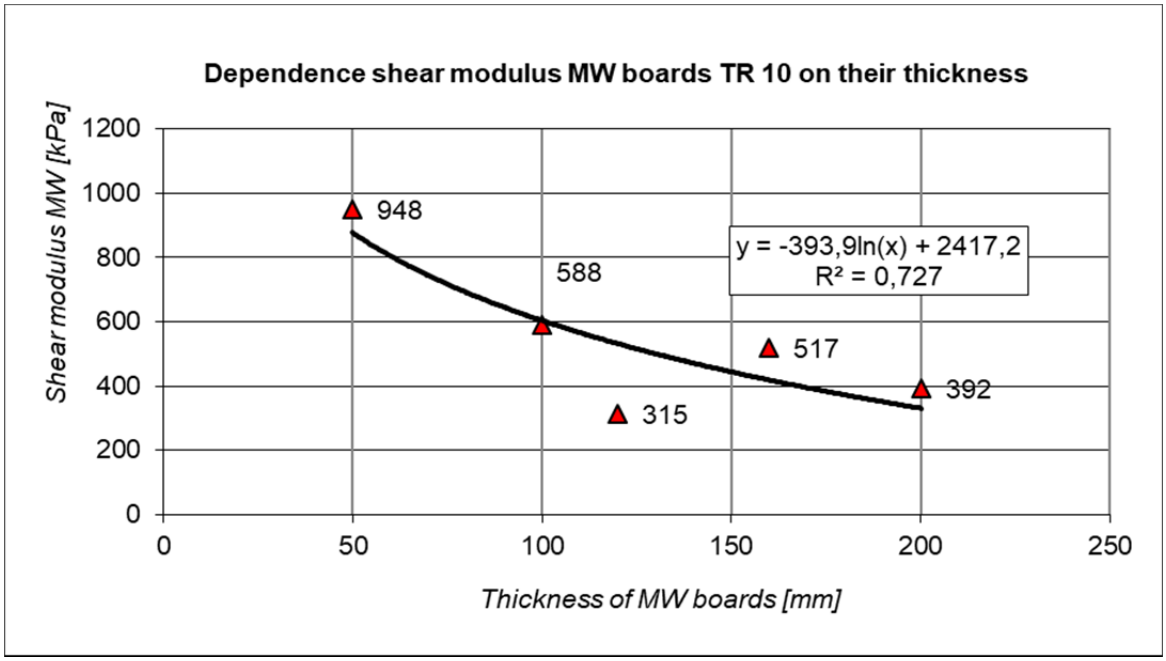
Nominal thickness [mm]	Shear behaviour [kPa]	Shear modulus [kPa]
50	57	1100
100	41	1320
120	45	1280
160	35	1100
200	22	858

8.1 Regression dependence shear characteristics on MW board thickness

Following graphs are exposing regression dependence average test values determination of shear characteristics MW boards – TR 10 on their thickness, for dimension of specimen (200 x 100) mm forming double specimen test sample.



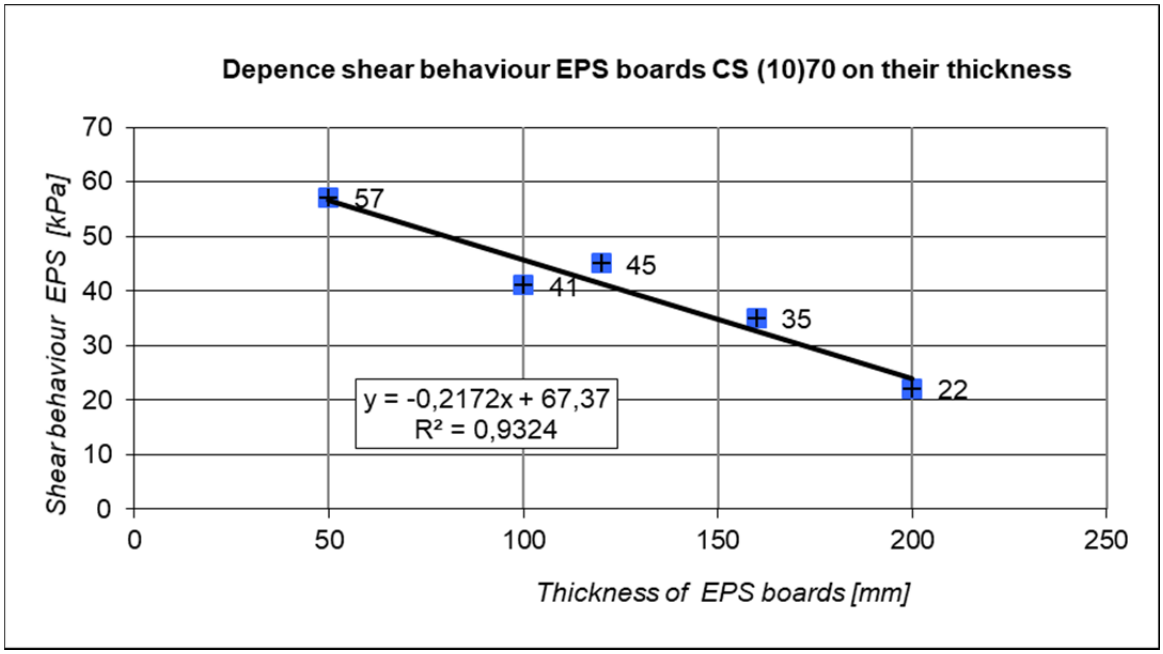
Graph 1. Regression reference dependence shear behaviour MW boards TR 10 on their thickness for dimension of specimen (200 x 100) mm - double specimen test sample



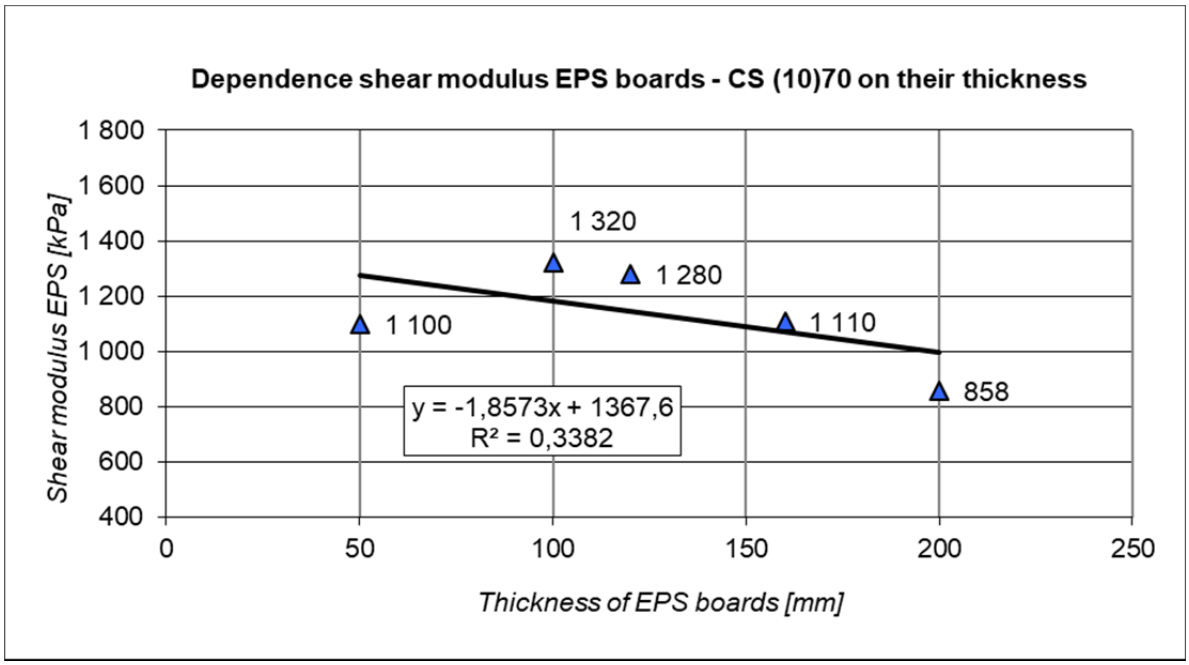
Graph 2. Regression reference dependence shear modulus MW boards TR 10 on their thickness for dimension of specimen (200 x 100) mm - double specimen test sample

8.2 Regression dependence shear characteristics on EPS board thickness

Following graphs are exposing regression dependence average test values determination of shear characteristics EPS boards – CS(10)70 on their thickness, for dimension of specimen (200 x 100) mm forming double specimen test sample.

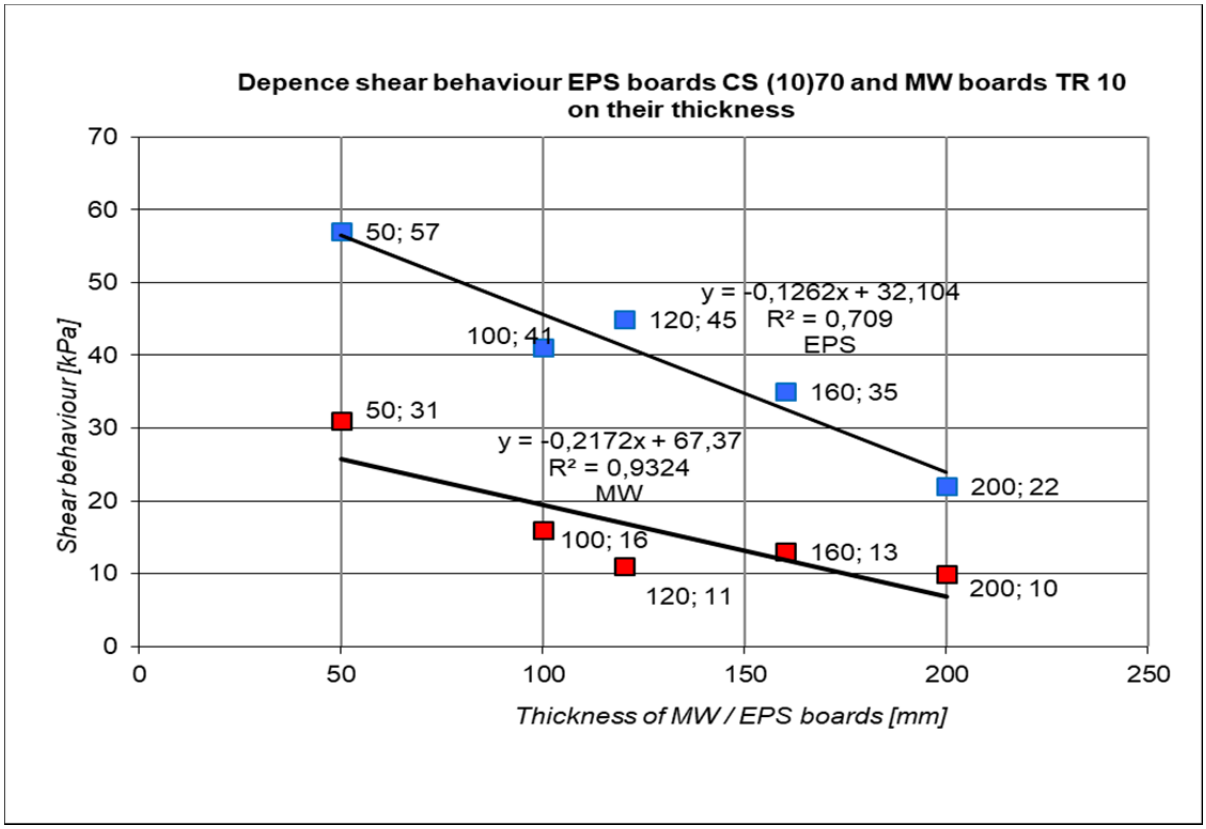


Graph 3. Regression reference dependence shear behaviour EPS boards CS(10)70 on their thickness for dimension of specimen (200 x 100) mm - double specimen test sample

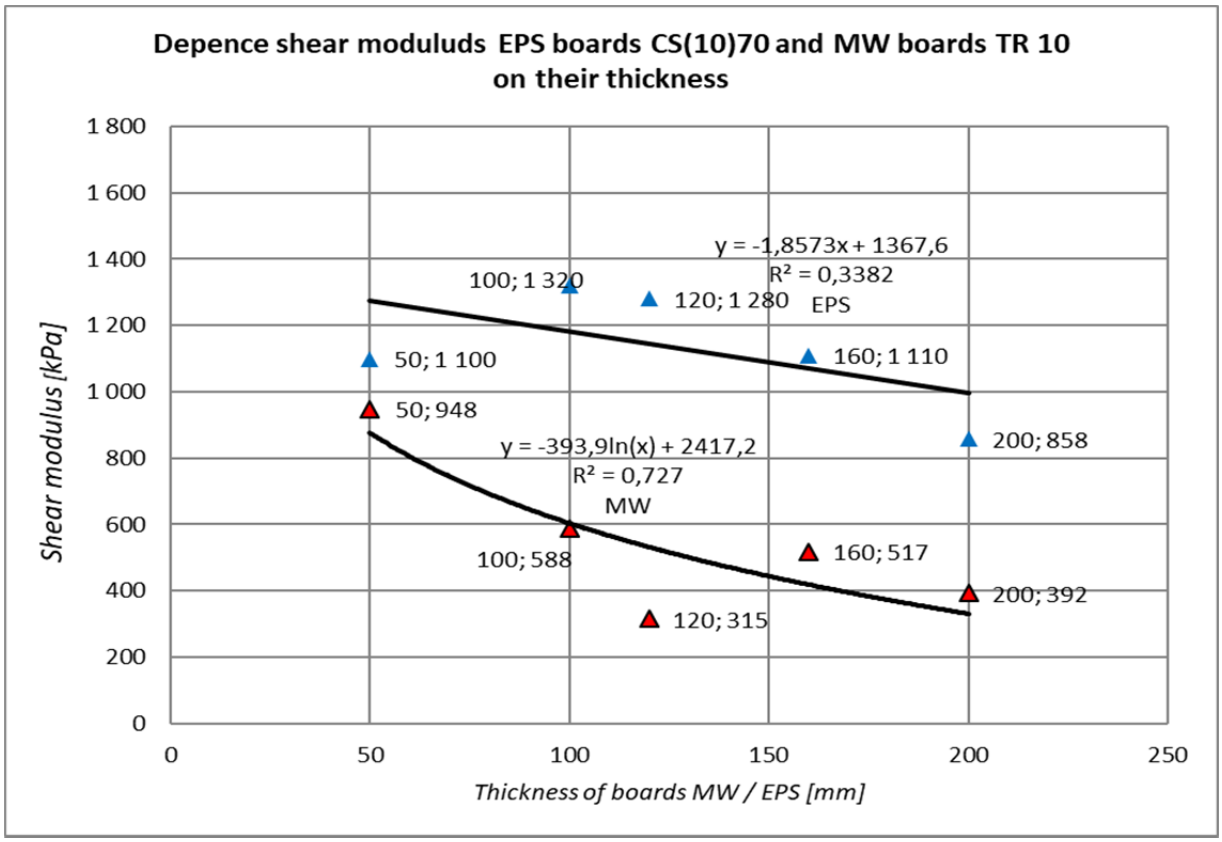


Graph 4. Regression reference dependence shear modulus EPS boards CS(10)70 on their thickness for dimension of specimen (200 x 100) mm - double specimen test sample

Following graphs are exposing dependence of shear characteristics in common graph.



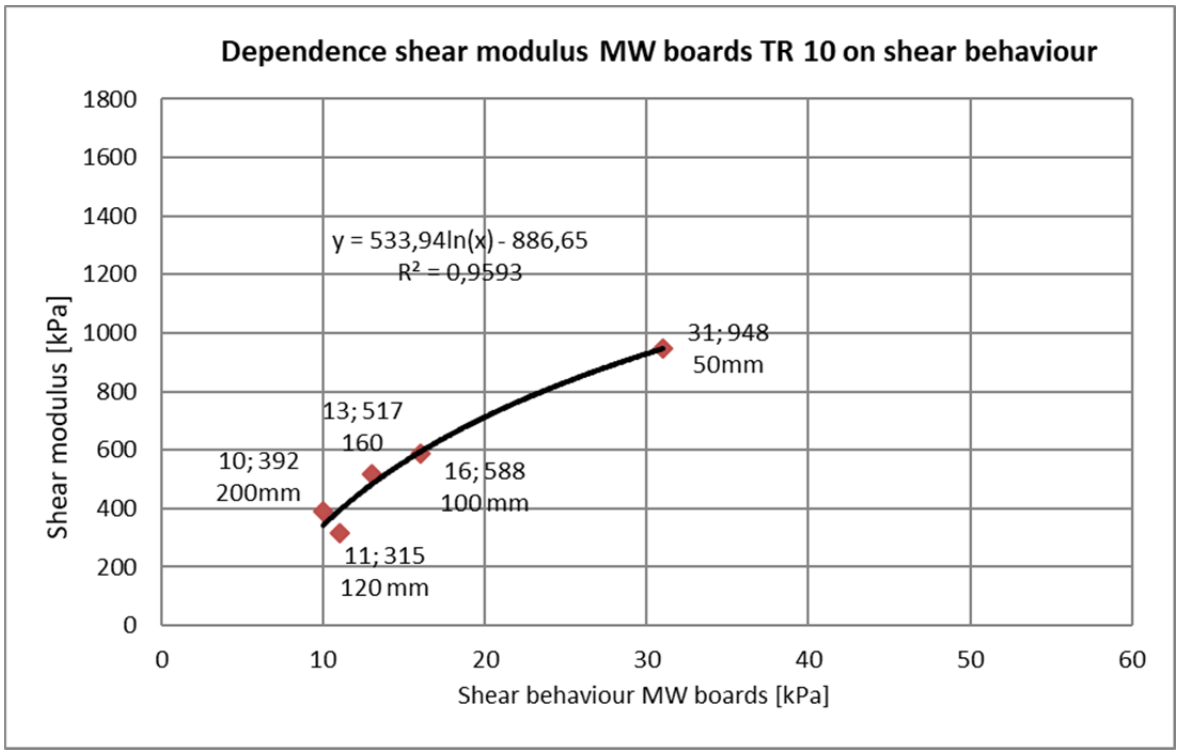
Graph 5. Regression reference dependence shear behaviour EPS boards CS(10)70 and MW boards TR-10 on their thickness for dimension of specimen (200 x 100) mm - double specimen test sample



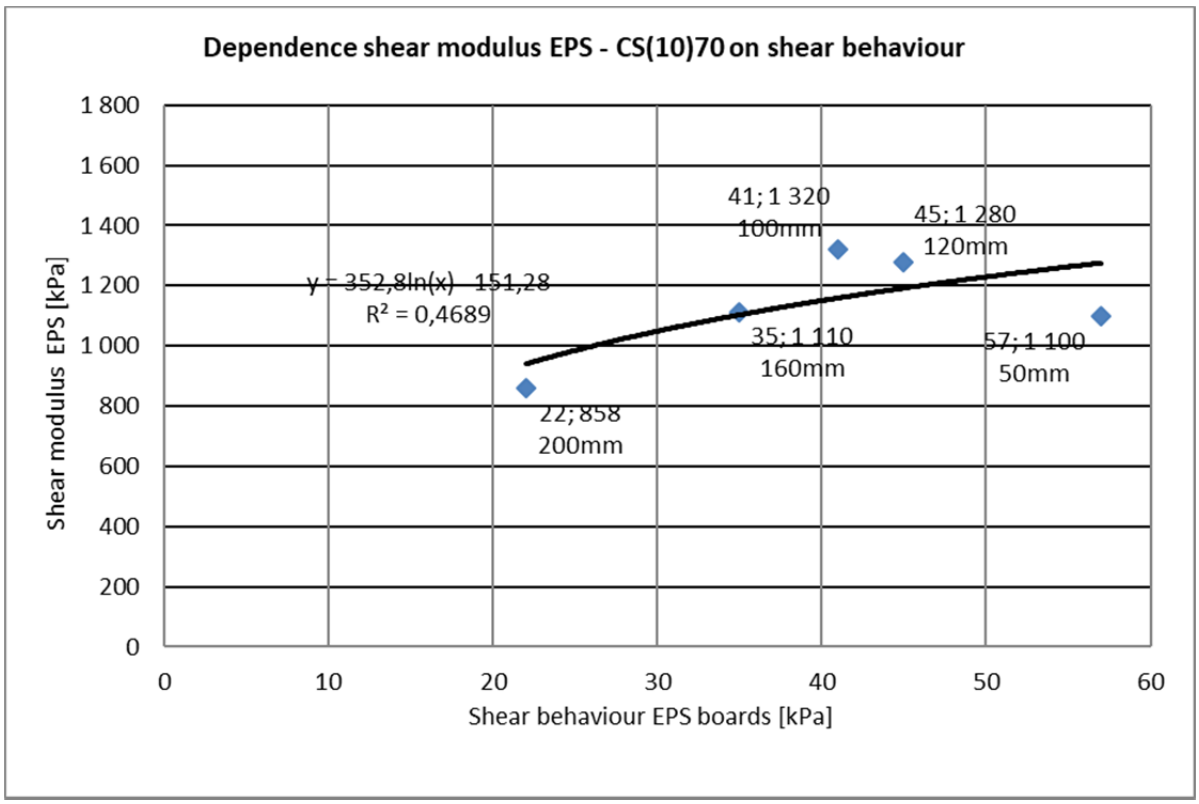
Graph 6. Regression reference dependence shear modulus EPS boards CS(10)70 and MW boards TR-10 on their thickness for dimension of specimen (200 x 100) mm - double specimen test sample

8.3 Interdepencies shear characteristics of MW and EPS boards

Following graphs are exposing regression reference dependence shear characteristics MW boards TR-10 and EPS boards CS(10)70 on their thickness for dimension of specimen (200 x 100) mm - double specimen test sample in range of thicknesses specimen 50 mm – 200 mm, for identical declared tensile strength perpendicular to faces MW – 10 kPa, resp. declared identical value of compressive behaviour by 10% compression EPS – 70 kPa. **For comparision are graphs in the same parting of axis.**



Graph 7. Interdependencies shear characteristics of MW boards TR 10 in range of thicknesses (50 -200)mm for identical declared value tensile strength perpendicular to faces 10 kPa, dimensions of specimen (200x100)mm



Graph 8. Interdependencies shear characteristics of EPS boards CE(10)70 in range of thicknesses (50 -200)mm for identical declared value compressive behaviour by 10% compression 70 kPa, dimensions of specimen (200x100)mm

9. CONCLUSION

Product standards ČSN EN 13162 (MW) and ČSN EN 13163 (EPS) prescribe different dimensions of specimen for determination shear characteristics. ČSN EN 13162 (MW) prescribes dimensions of sample for „double specimen test“ (200x100) mm x thickness of product, without limit for thickness. ČSN EN 13163 (EPS) prescribes dimensions of sample for „double specimen test 50 mm x 250 mm x thickness 50 mm, so maximal thickness is 50 mm for all thicknesses of produced EPS boards. Shear characteristics of EPS boards are considered to be identical in relation to representative value determined on board with 50mm thickness.

Determination of shear behaviour and calculated shear modulus was performed on test specimen with dimension 200 mm x 100 mm x thickness of product, forming half of „double specimen“ sample in accordance with ČSN EN 12090 for both – MW boards and EPS boards – to make possible comparison of results and trends of dependencies.

It was performed determination of dependence shear characteristics of thermal insulations made of MW and EPS boards on thickness of products/ specimen. It was determined 10 values of shear behaviour with following calculated evaluation of shear modulus for each thickness of MW/EPS boards, including identification tests of EPS and MW boards.

Measured data were used for statistical analysis for identification outlying values and after that was determinated regression dependence of shear characteristics MW and EPS on thickness of products/specimen, for identical types of products with compressive behaviour by 10% compression EPS 70 kPa (CS(10)70) and tensile strength perpendicular to faces MW 10 kPa (TR10).

Regression analysis were performed for whole range of thicknesses of specimen. From results is clearly seen trend of decreasing values of shear characteristics for EPS and also MW by increasing thicknesses in whole range thicknesses of boards 50mm – 200 mm. Difference of values for marginal thicknesses is multiple. This phenomenon is possible to assign as well to influence of standard test method and to size of test specimen in accordance to product standards on test results. For higher thicknesses of products/specimen appears inappropriate size of specimen, when thickness of specimen is considerably exceeds its width and approach to its height. Test result apparently then does not respond to real characteristics of product ensure safe proposal of ETICS. Specimens have not shape of board yet, when thickness is substantially smaller than other dimensions. From progress of tests of shear characteristics for samples with higher thicknesses was apparent, that test sample is not burden only by clear shear, but by combination shear/load/compression.

From test results and graphs of dependencies is possible deduce substantial influence for this analysis chosen identification parameters on shear characteristics. Listed dependencies were not published in available technical documents in that range.

Experimental results flowing from solving of project proved substantial difference between values of shear characteristics by application of standard test method, which was not appar-

ently validated for higher thicknesses of products used currently for ETICS, when EPS and MW boards are forming static effective layer of ETICS transmitting burden to base and commonly are used with thickness 200 mm or more for insulation buildings ETICS. From test results is not possible clearly deduce proposal values of shear characteristics for MW/EPS boards for design of ETICS. By this is not said, that shear characteristics MW/EPS boards are not dependent on thickness.

10. RECOMMENDATION

By using results of this project perform research of dependence of shear characteristics for EPS/MW on specimen with ratio of sizes the edges is corresponding with tested product with board shape so thickness of specimen is not higher than one of area dimension of specimen by using apparatus for testing in accordance with ČSN EN 12090 with modification to minimalize combination of burden of specimen. By using test results on basis new information of this project determined dimension/dimensions of specimen forming „double-specimen“ sample in dependence on thickness of product as base for determination real, not apparent values of shear characteristics of EPS/MW boards for ETICS design.

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Authors of report: Ing. Lubomír Keim, CSc.

Ing. Tomáš Langer

11. ANNEX

Figures of double-specimen test sample of MW and EPS, thickness of specimen 120 mm.

Photo by upper view

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