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Adhesion and Cohesion Testing of Joint Sealants after Artificial Weathering – New Test Method

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Abstract

The use of construction sealants is an important area not just of the building construction. Each building requires a careful processing of all details and façades are no exception. From today´s point of view we may note that sealing of façade joints and different types of cracks, fissures or gaps is nothing unusual and, therefore, it is astonishing that there still occur defects that often cause a significant decrease of the durability of the structures and sealed structures. This paper deals with testing of a selected group of construction sealants at a so-called '*real joint*'. The real joint is a term defining a set of testing samples when the testing body contains a sealant applied in a manner corresponding to its real application. Cement bonded particleboard board was representing the façade cladding in this research since during the sealing there often occur complications with adhesion of sealants. For the presented experiment the existing testing methods that are used for verification of adhesion of cladding materials were studied and modified. According to the opinion of the authors those modified methods simulate well the parameters of the external environment and thus also the negative influences that may have a significant impact on the sealed joint in practice. The measured results prove that in the application of the sealants it is very important to follow the technology discipline and namely it is necessary upfront to verify whether the chosen materials are compatible. In most tested cases, diversion from the above-given steps resulted in failure of the sealed joint.

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1. Introduction

The use of construction sealants is an important area not only of the building construction. No matter whether it is a building or a road, each structure requires a careful processing of all details and façades, that are the main focus of the presented research case, are no exception [1, 2]. From the present perspective, we may note that sealing of façade joints, gaps or cracks is nothing unusual [3 - 6] and therefore it is surprising that there still occur defects that often cause significant decrease in the durability of the structures as well as of joined parts of structures.

According to the opinion of the authors, existing testing procedures intended for testing of bonded and sealed joints do not fully reflect the abrupt weather changes exterior surfaces are subject to [7 - 10], moreover, they also often prescribe unsuitable geometry of the testing samples [11, 12]. The aim of the authors was to create a testing sample of such a shape that would correspond as much as possible to the real implementation of the sealed joint and subsequently to put it through tests that would verify the impact of the external environment on its rheological and mechanical properties [13, 14].

Based on previous experiences [15, 16] a unique geometry of testing sample was created for this purpose allowing the testing of a so-called '*real joint*'. The real joint is a term which, according to the opinion of the authors, suitably reflects the applied geometry of testing samples as well as the procedure of their assembling. This is a sealed joint when the sealant or any other filling material is applied in a way corresponding to the real application, as can be seen in Fig. 1.

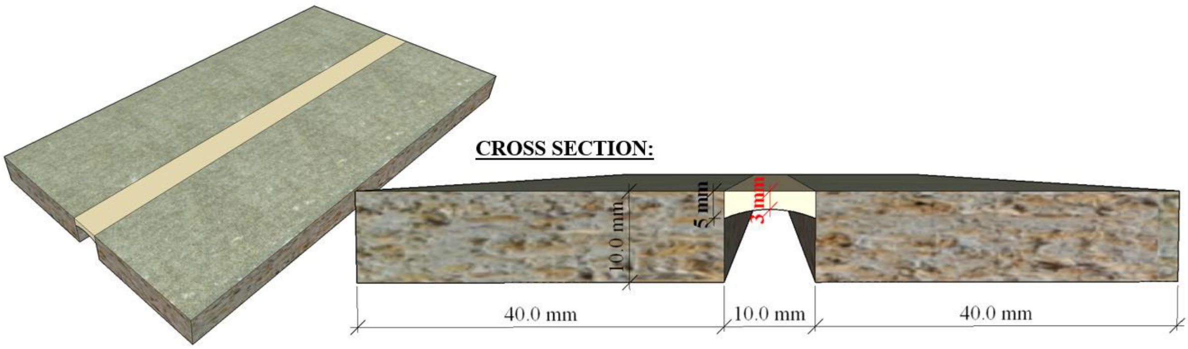

Fig. 1. Real joint design.

Since this is an entirely unique testing of the bonded joint it was necessary to create new testing equipment allowing the measuring of deformations at the maintained extension. For this purpose, testing molds were produced allowing to maintain constant extension for an arbitrarily long time. Further, it was necessary to take into account dimensional changes of the joint due to the changing temperature and the joint movement (i.e. extension or compression) and therefore, two different testing molds were designed allowing the verification of the bonded joint under different conditions at normal (i.e. tensile) and shear stress.

2. Experimental

The presented work comprised two parts. First, the maximum elongation of the tested sealants at break was evaluated by extension test. Second, the failure mode that appeared during testing was observed to express the compatibility of tested materials.

2.1. Materials

Currently, an inexhaustible quantity of materials is available on the market allowing to join, fill in and seal joints. Materials are suitable both for bonding in the interior as well as in the exterior. The selection of material for this test was based on an already completed project which was also dealing with the issue of bonded cladding of ventilated façade systems [17] and, therefore, only selected building sealants and adhesives manufactured by the same producers as for the adhesive systems were tested. Cetris Basic board has been selected as the representative of the façade cladding that was also tested in the previous project. At the present time, the cement bonded particle board is a very popular type of façade cladding and not only because of its low price but also thanks to the minimum requirements for the regular maintenance [18]. As suggested by the name, the Cetris board is a composite material the main components of which are cement and wooden chips. Although it is a very durable material, the disadvantage that is the result of the composition of the cladding is higher linear expansion by the air humidity change that is mainly caused by the content of wooden chips. In the case of the joints bonding, these changes may represent a major problem and may cause the damage to the sealed joint [13 - 14, 19].

Also selection of tested sealants was based on previous experience [17, 20] therefore, only one-component polyurethane or modified polymer sealants were tested, more information about their rheological and mechanical properties can be seen in the Table 1. An indispensable advantage of the selected modified polymeric sealants, in this case STP and SMP, is their minimal environmental burden in comparison to polyurethane materials. In some European countries such as e.g. Belgium or the Netherland, the use of polyurethane sealants and adhesives is limited or even forbidden since the adhesives themselves or their primers that are very often used in the PU systems contain toxic cyanides. On the contrary, a major disadvantage of modified polymers in comparison to polyurethanes is lower elasticity and very often also unpredictable adhesion to bonded surfaces.

Table 1. Comparison of Relevant Material Properties.

Sealant	Polyurethane		STP*	Silyl Modified Polymer	
	Type I - 1	Type I - 2	Type II	Type III - 1	Type III - 2
Tear Strength [N/mm^2]	1.5	2.2	2.1	2.6	2.5
Elongation at Break [%]	> 700	> 600	c. 200	c. 250	c. 250
Elastic Recovery [%]	> 80	unknown	unknown	15	15
Service Temperature [°C]	- 40° to +80°	- 40° to +90°	- 40° to +80°	- 40° to +100°	- 40° to +80°

* STP abbreviation for Stress Tolerant Polymer

2.2. Methods

As already mentioned above, the authors of this paper share the opinion that certain standardized testing procedures do not quite correspond to the real weather changes to which the façade elements are often exposed. Therefore, certain testing methods have been adapted and modified and also two methods of conditioning of the testing samples that are used as a standard to determine the adhesion of the cladding to load-bearing substructure were applied.

2.2.1. Test Sample Geometry, Manufacturing and Curing

Dimensions of test samples were determined based on previous experience and boards of 40 x 160 mm were made from the Cetris Basic cladding of 10 mm thickness. The sample geometry can be seen in Fig. 1. The thickness and width of the sealed joint was based on the recommendations specified by the manufacturer of the façade cladding [18]. The basic width of the joint was (10 ± 0.5) mm and thickness was 3 – 5 mm. To prevent the occurrence of so-called three-sided adhesion that might be the cause of an uneven stresses on the elastic filling before the application of the sealant, a polyethylene foam string the thickness of which corresponds to 1.2 multiple of the thickness of the joint that is being sealed was applied into the joint.

Preparation of the samples and subsequent application of the sealant was carried out according to the principles and procedures specified by the producers of the individual system. Generally, the edges of all samples were cleaned of dust and potential grease using cleaning products of the given system before the actual sealing was performed. To achieve maximum adhesion, it was necessary in certain cases to use an improving coating liquid or so-called primer, namely with Type I – 1, Type I – 2 and Type III - 1. Nine test samples were produced for each test method i.e. for testing of normal stress as well as shear stress. Therefore, for each tested temperature of the environment 6 test samples were conditioned.

During curing period test samples were stored in a dry and clean environment so that they aged sufficiently. Their ideal aging occurred in less than 72 hours. However, to achieve sufficient strength and resistance of sealants, testing and conditioning was only commenced after the passing of 28 days which is condition stipulated by many international standards [13]. The test samples subjected to testing without conditioning, i.e. 3 samples for normal stress and 3 samples for shear stress, were tested immediately after these 28 days.

2.2.2. Conditioning

The test samples were subjected to two methods that may influence the resulting behaviour of the real joint in the exterior since these methods simulate weather changes. The principle of the first method is the alternate heating of test samples with infrared lamps to the temperature (70 ± 2) °C and their subsequent cooling with a water shower to the temperature of (23 ± 2) °C [21].

The second method [22] is based on alternate freezing of the test samples to the temperature of (-22 ± 2) °C and their subsequent thawing by immersing into a water bath at the temperature of (23 ± 2) °C. The immersion into the water bath took 6 hours and subsequently the samples were kept for 18 hours in a freezing chamber.

2.2.3. Testing

Before the testing itself, the measuring of the width of the real joint was performed in all samples, see results presented in Fig. 2 Subsequently, the test samples were placed into test moulds and extended at a speed of approximately (5.5 ± 0.7) mm/minute. The testing was performed in the following steps:

- A. Extension of the '*real joint*' to 100 % of the original width;
- B. Studying of changes at 100 % extension for the period of 24 hours;
- C. After 24 hours, extension of the '*real joint*' was conducted until its failure.

Stretching was applied until 100% elongation of the original length, that is twice the width of the real joint in the case of normal extension, however, not in case of shear extension. Samples prepared in this manner were left in the testing mould for the period of 24 hours. If no failure of the sample or the bonded joint was observed during these 24 hours, a further extension was commenced until the sample failure. During testing also the failure modes were recorded, see Table 2. and Table 3.

3. Results

Although it was noted at the beginning of this paper that the main objective of the new test method is to establish compatibility of the selected materials that is very easy to determine based on visual monitoring of the changes during the extension of the sealed joint, its secondary objective was to establish the size of the real joint deformation which in this case is represented by its relative elongation. The relative elongation of the real joint was determined based on a formula (1).

$$\varepsilon = \frac{\Delta l}{l} \tag{1}$$

where ε is relative elongation [-], Δl is a change of joint width in mm and l is the original joint width in mm.

The relative elongation represents the ratio of the width change of the real joint to its original dimension. According to the character of the stress, there may occur either relative contraction or relative elongation. Based on the established relative elongation, it was possible also to determine tensibility of the tested sealants. Tensibility was expressed in percentage of the original width of the sealed joint according to the formula (2).

$$\delta = \frac{\Delta l}{l} \times 100\% \quad (2)$$

where δ is tensibility [%], Δl is a change of joint width in mm and l is the original joint width in mm.

Table 2. Comparison of test results – Test samples tested under normal stress.

Tested Sealant	Maximum Elongation at Break [mm]			Average Maximum Elongation at Break [mm]	Tensibility δ [%]			Average Tensibility δ [%]	Type of Failure Mode**	Percentage Failure Rate [%]
	W	STC	FR*		W	STC	FR*			
Type I - 1	44.21	37.45	57.17	46.28	269.6	200.6	386.4	285.5	CF; A/CF	89; 11
Type I – 2	62.43	21.38	39.21	41.01	452.6	100.0	254.4	269.0	CF	100
Type II	16.37	14.38	12.40	14.38	53.5	40.1	28.1	40.6	AF; CF; A/CF	67; 22; 11
Type III – 1	18.43	16.83	15.23	16.83	63.2	46.4	30.0	46.5	AF; CF	89; 11
Type III - 2	21.83	20.87	19.91	20.87	89.9	74.6	60.1	74.9	AF; CF; A/CF	22; 56; 22

*W – Without Conditioning; STC – Sudden Temperature Changes; FR – Frost Resistance;

**AF – Adhesive Failure; CF – Cohesive Failure; A/CF – Combination of Adhesive and Cohesive Failure;

Table 3. Comparison of test results – Test samples tested under shear stress.

Tested Sealant	Maximum Elongation at Break [mm]			Average Maximum Elongation at Break [mm]	Tensibility δ [%]			Average Tensibility δ [%]	Type of Failure Mode**	Percentage Failure Rate [%]
	W	STC	FR*		W	STC	FR*			
Type I - 1	41.97	44.62	35.77	40.79	356.7	392.8	312.5	354.00	CF; A/CF; FTF	78; 11; 11
Type I – 2	48.07	20.67	32.99	33.91	435.2	204.0	311.8	316.99	CF; NF	78; 22
Type II	10.40	7.88	5.37	7.88	100.0	76.8	55.5	77.44	AF; CF	67; 33
Type III – 1	9.30	7.84	6.71	7.95	89.4	73.3	61.6	74.79	AF	100
Type III - 2	11.47	10.92	6.71	10.82	103.9	100.9	63.1	100.15	AF; CF; A/CF	44; 44; 11

*W – Without Conditioning; STC – Sudden Temperature Changes; FR – Frost Resistance;

**AF – Adhesive Failure; CF – Cohesive Failure; A/CF – Combination of Adhesive and Cohesive Failure; FTF – Fiber - Tear Failure

4. Analysis

The width of the real joint was measured before the commencement of the testing so that it was possible to determine firstly whether there occurred a deformation of the sealants during the curing or conditioning and also so that it was possible to determine the relative elongation/shrinkage of the real joint during its curing or after conditioning. The width of the real joint was measured in three points with the use of Vernier callipers. The measured values were averaged and a representative width of the sealed joint was obtained, as can be seen in Fig. 2. on the left side of the chart. On the basis of this average value, and also with respect to the original width of all samples that was (10 ± 0.5) mm, a so-called normalized value of the joint width was determined.

The normalized value less than 1 indicates that the joint sealant was in a compressive state and a normalized value close to 0 indicates more compression of the joint sealant with respect to the original width. Values higher than 1 prove the elongation of the real joint. The normalized value is a very complex parameter based on which it is possible to define the relative shrinkage of the tested joint in cases when more different widths of the joint are being tested.

The average values of joint width range from 9.63 mm to 12.05 mm, as shown on the left side in Fig. 2, and from 0.95 to 1.04 in terms of average normalized value, as shown on the right side in Fig. 2. The presented data show that curing as well as conditioning actually have a significant effect on the sealed joint when in some case, namely Type I – 2 and Type II, the real joint shrank considerable. For example, the data measured for Type I – 2 show that according to the normalize value the real joint measured after curing elongated, however, when the samples were measured after conditioning to sudden temperature changes a shrinkage was observed, moreover there was not observed any changes in joint width when measured after conditioning to the frost resistance. In other cases, it was possible to observe opposite tendencies, mainly in case of sealant Type III – 2. where have not been observed any changes after conditioning to sudden temperature changes. The normalized value can help to find an appropriate combination of sealant and cladding material, mainly when porous cladding is used.

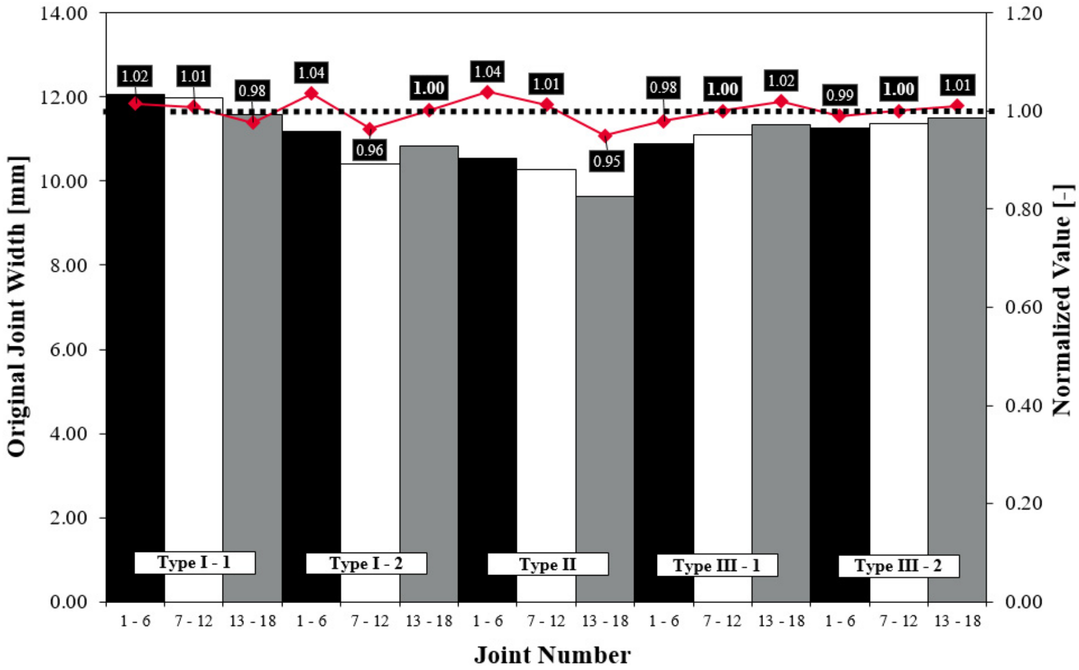

Fig. 2. Evaluation of joint width changes - black columns and samples numbered 1 - 6 are representing samples which were tested immediately after curing, white columns numbered 7 - 12 are samples tested after conditioning to sudden temperature changes and grey columns numbered 13 – 18 are samples tested after conditioning to the frost resistance.

Since the objective of this research was not the measuring of force in applying of which failure of the joint will occur but monitoring of the failure modes and measuring of the maximum possible elongation of the tested sealants, it was necessary for this purpose to create a scale that would include all probable ways of failure of the real joint. The scale of seven different failure modes was made up based on the ČSN ISO 10365 standard and international ASTM D 5573 standard. However, as can be seen in Table 2. and 3. basically only three different failure modes were monitored. Since the Cetris cladding is composed of chips connected by mainly cement, therefrom the name is derived – the cement bonded particle board, it was necessary also to include into the list of possible failure modes the failure that anticipates the tearing of fibres (chips) of the cladding. It follows from the above results that not all selected sealants, namely Type II and Type III – 1, are compatible with the selected Cetris façade cladding, which has also confirmed one of the hypothesis of this research.

It is evident from the results presented in the Table 2. and Table 3. that both tested polyurethane sealants obtained the best results of the tested group when even during the conditioning, no marked deterioration of tensile properties of the materials occurred. The most frequently recorded mode of failure in this group was damage by cohesion which occurred only under major tensile stress of the joint and yet, the maximum elongation stated by the producers was not achieved in a single case. It was also noted for sealant Type I – 2 that after conditioning, the joint got contracted more often than in the case of Type I – 1 and also the achieved elongation was lower than in the samples, in which conditioning was not conducted. Reduced elasticity of the sealant due to temperature changes was discovered both in normal and in shear stress of the joint. In the case of normal stress, the identified deviations were even greater than in shear stress of the joint. After freezing cycles, there occurred average decrease of elasticity in normal stress by 43.8% and by 28.3% in shear stress. Values identified after cycles of temperature changes were even higher. The average reduction of the bonded joint´s tensibility was reduced by 77.1% and in the case of shear stressed sample by 53.1%. These results confirmed another hypothesis that the properties of bonded joints lose their elastic properties due to aging and impact of the environment. It is probable that a longer impact of the environment changes could have a more significant impact on the elasticity of the tested material.

Fig. 3. Failure modes observed during testing.

In the case of polyurethane sealants, there occurred a failure of adhesion between the sealant and cladding in several cases only as can be seen in Table 2. and 3. The failure of adhesion occurs most frequently in cases when the connected materials are not compatible or if dust or other smaller particles are found in the joint that is being bonded that are the cause of poor adhesion of the sealant to the cladding. In this case, the insufficient adhesion could have been caused by the poor cleaning of the bonded surfaces. Good adhesion of the selected sealants was also enhanced with the use of improving coating by the given producers.

Contrarily, in the case of the Type II sealant, which was the only tested representative of the stress tolerant polymers group, a very small elongation was achieved and again, it was possible to see the negative impact of temperature changes on the real joint. In the group of test samples that were not conditioned, there occurred cohesion failure of the joint in 5 cases out of 6. Contrarily, in samples that have been conditioned, adhesion failure occurred in almost all cases. In this case, it was rather a failure of compatibility of the bonded materials. This fact may be followed in the failure mode of samples in the Table 2. and 3. Also for these reasons, the tested sealant is more suitable for the application in less stressed joints, in which their impermeability needs to be primarily safeguarded.

The last tested group of sealants were so called silane-modified polymers. Results identified in a universal sealant and adhesive in one, marked Type III – 1 in this paper, were not an immense surprise. It was already known from the results of the previous project that it was quite a good adhesive with very poor elastic properties and, therefore, the researchers did not even expect that it could be a suitable sealant for filling of the real joint. As it is obvious from the results given in Tables 2. and 3., there was adhesion failure in almost all tested sample and at least 100% prolongation of the joint was achieved in several cases only. Therefore, it is possible to note that this material is not suitable for filling of joints.

On the contrary, the results recorded in the second representative of the MS polymers, in this paper marked as Type III – 2, were more than satisfactory. Although the sealant was not too elastic and prolongation to 100% of the original width was again achieved only in just a few instances, its adhesion to the selected cladding was very good. As results in the tab. 3 show, cohesion failure of the joint occurred in more than 52% or there was a combination of adhesion and cohesion failure.

5. Conclusion

This paper presents the idea of a new method for testing of sealants in the application corresponding to the real implementation of the bonded joints. These are not standardized testing procedures but verification of adhesion and cohesion in stressing the testing sample made out in the form of a really designed joint. For this reason, according to the opinion of the authors, it will not be necessary systematically to apply the above-mentioned procedures for all combination that are on offer like in the case of standardized tests. It follows from the measured values that these new procedures bring interesting findings and namely they offer a complex testing of the bonded joint, which is often neglected in the standardized tests. Complex evaluation of the results of the presented group of tests further showed that despite the polyurethane sealants are not very environmentally friendly, they achieve much better results in comparison to the sealants based on modified polymers both with regard to their adhesion to the cladding or base when the most frequently identified mode of failure was cohesion both with respect to their elasticity and subsequently also permanent deformation. Therefore, from the long perspective, polyurethane sealants seem to be a guarantee of impermeable joint in the case of highly stressed joints.

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References

[1] K. W. Allen, A. R. Hutchinson, A. Pagliuca, A study of the curing of sealants used in building construction, in: International Journal of Adhesion and Adhesives, Vol. 14. Issue 2. (1994) 117-122.
[2] I. Takeshi, A. Gustavsen, B. P. Jelle, Sealant aging and its correlation with facade reflectance, in: Construction and Building Materials, Vol. 69 (2014) 390-402.
[3] M.Y.L. Chew, L. D. Yi, Elastic Recovery of Sealants, in: Building and Environment, Vol. 32. No. 3. (1997) 187-193.
[4] G. Krüger, G. E. Völkel, Actual Problems of Structural Sealant Glazing, in: Otto-Graf-Journal Vol. 9. (1998) 95–113.
[4] M. Y. L. Chew, Joint sealant for wall cladding. Polymer testing scientific journal. Published by Elsevier Science Ltd. in 2000. pp. 653-665.
[6] A. R. Hutchinson, T. G. B. Jones, Effect of cladding panel movement on the performance of newly sealed joints, information on: <http://www.bath.ac.uk/cwct/cladding_org/icbest97/paper26.pdf>, pp. 211.
[7] M. Z. L. Chew, X. Zhou, S. T. Tan, On-site weathering of sealants under tropical conditions, Construction and Building Materials, Vol. 18, Issue 4, 2004, pp. 287-293.
[8] H. Stögbauer, A. T. Wolf, The influence of heat ageing on one-part construction silicone sealants, Construction and Buildings Materials, Vol. 5, Issue 1, 1991, pp. 27-32.
[9] M. Y. L. Chew, On-site non-destructive test for sealant. Polymer testing vol. 19. Published by Elsevier Science Ltd. in 2000. p. 643-651.
[10] L. F. M. da Silva, R. D. Adams, Adhesive joints at high and low temperatures using similar and dissimilar adherends and dual adhesives, in: International Journal of Adhesion and Adhesives. Vol 27. I. 3 (2007). pp. 216-226.
[11] Q. Li, R. Crowley, D. Bloomquist, R. Roque, Newly Developed Adhesive Strength Test for Measuring the Strength of Sealant between Joints of Concrete Pavement. J. Mater. Civ. Eng., 26(12), 2014.
[12] A. Pagliuca, A. R. Hutchinson, Durability of resealed building joints, in: Proceedings of the International RILEM Symposiu, First Edition, 1996.
[13] M.Y.L. Chew, Curing characteristics and elastic recovery of sealants, in: Building and Environment Vol. 36. No. 8. (2001) 925–929.
[14] A, T. Wolf, Movement capability of sealants, in: Construction and Building Materials Vol. 5. (1991) 127–134.
[15] B. Nečasová et al., Test of Adhesion and Cohesion of Silicone Sealants on Facade Cladding Materials within Extreme Weather Conditions, in: Advanced Materials Research. Vol. 1041. (2014) pp. 23-26.
[16] B. Nečasová et al., Case Study on Determination of Tensile Properties of Construction Sealants at Variable Temperatures, in: Applied Mechanics and Materials. Vol. 824. (2016) pp. 18-26.
[17] B. Nečasová, P. Liška, J. Šlanhof, Research Summary: Verification of Adhesively Bonded Façade Joints, in: Proceedings of ESaT 2016 2nd International Conference on Engineering Sciences and Technologies. (2016).
[18] CIDEM Hranice a.s., division Cetris, 2014. “Basic Properties of CETRIS – Cement Bonded Particleboard”, available from: <http//cetris.cz>.
[19] A. Franco, G. Royer-Carfagni, Contact stresses in adhesive joints due to differential thermal expansion with the adherends, in: International Journal of Solids and Structures Vol. 87. (2016) pp. 26-38.
[20] J. Šlanhof, P. Liška, M. Šimáčková, B. Nečasová, Sealing Possibilities for Wood Elements, in: Proceedings of People, buildings and environment, Kroměříž, 2014.
[21] Czech Standards Institute, ČSN 73 2581: Test for resistance or surface finish of building structures to temperature variations, Prague, 1983.
[22] Czech Standards Institute, ČSN 73 2579 - Test for frost resistance of surface finish of building structures, Prague, 1981.