

Sealing of Joints in Steel Structures without Surface Treatment

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Abstract—This contribution deals with the possible options for the sealing of joints which occur in steel structures without surface treatment. The aim is to obtain a means of sealing joints with the potential for long-term reliability without adhesive and cohesive failures that can then lead to the penetration of undesired humidity into the structure. The task is approached experimentally using test procedures based on current European technical standards. The test substructure, which represents a steel substructure, is made up of CORTEN facade panels intended for the final cladding of buildings without any further surface treatment. A group of 10 industrially-produced, commonly available sealants from 3 manufacturers are included in the experiments. The research brought an answer to the question of the sealability of an unprocessed steel substructure and also solved the issue of the type of sealant most suitable for this purpose.

Keywords—Adhesive Failure, Cohesive Failure, Extension, Maintained Extension, Seal, Sealant

I. INTRODUCTION

At present, sealants are very common materials used mainly for the filling of joints in structures. These aren't load-bearing structural joints; what is being considered here is the sealing of joints. Sealants are defined as materials applied in a form which isn't molded in advance and which is able to seal a joint after hardening or drying due to its adhesive and cohesive properties. 'Sealing' means the placement of a suitable product into a joint in order to prevent the penetration of water, moisture or air between structural elements, parts or components made from identical or different materials. Sealants used in facades are stressed by the impacts of aspects of the climate, i.e. by frequent alternation of dryness and humidity, and significant temperature fluctuations and the changes in substructure material length they cause. A suitably selected sealant must withstand the impact of the environment even in extreme conditions without suffering adhesive or cohesive failure.

II. LITERATURE REVIEW

Silicone sealants and adhesives as used e.g. in the construction industry were introduced approximately forty years ago. Their commercial importance is mainly based on their unique combination of material properties which permit them to satisfy important needs in a broad variety of markets. The most important properties of silicone sealants for

construction are durability and adhesion [1]. The effect of weather changes on the degradation of sealant joints has been studied and discussed in detail in the literature. The cause of sealant failure on a building facade depends on the type of sealant used and the quality of installation. Sealant material can fail due to improper curing, aging and weather exposure. Failure can also occur if large joint movements take place before the seal is fully cured [2]. Aging tends to manifest itself in the surface section of the test specimen instead of within the interior [3]. It has also been shown that long-term exposure to water and heat has an influence on the adhesive and cohesive failure of polyurethane sealants [4, 5, 6].

The authors of this article have tried to conduct a comprehensive literature review with the aim of comparing their own measurements with the results of other authors. However, no reasonable or more similar published works were found on the given topic. For these reasons, the research findings detailed below should be considered fully original.

III. METHODOLOGY

A. Selection of substructure material and tested sealants

The authors focused on the options for sealing a raw steel substructure with no surface treatment. Therefore, a 2-mm-thick steel sheet intended for façade cladding was selected as the substructure material. The steel has a reduced carbon content and is enriched with copper and phosphorus. Sheet cladding made from this material gains a characteristic, very impressive orange-coloured patina after a few years which resembles typical corrosion but which stays only on the surface and doesn't penetrate deeper. The product is known under the trade mark CORTEN. 10 products from 3 manufacturers were selected from the many commonly available sealants in such a way that sealants of various material compositions and differing price were chosen. A summary of the selected sealants can be found in Table I.

TABLE I. OVERVIEW OF SELECTED SEALANTS

Type of Sealant	Manufacturer		
	SOUDAL	Lučební závody Kolín, Czech Republic	SILCO
Silicone acetate	Universal silicone (SO-U)	Lukopren UNI A (LU-U)	universal silicone (SL-U)
Neutral silicone	SILIRUB N (SO-N)	Lukopren UNI N (LU-N)	neutral silicone (SL-N)
Polyuret hane	25D (SO-PU)	-	PU 40 (SL-PU)
MS polymer	SODASEAL 215LM (SO-MS)	-	MS 60 (SL-MS)

B. Manufacture of test specimens

The geometry of the test specimen is derived from current technical standards [8] - [11]. It consists of two substrate boards which are connected by a layer of sealant while complying with the fundamental requirement that the dimensions of the sealant be 12 x 12 x 50 mm. For the experimental part of the project, the test specimens were designed according to Fig. 1.

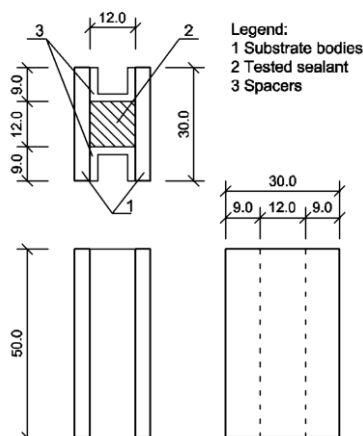


Figure 1. Test specimen

A sample prepared in this way is a lot more resistant to fracture due to the possibility of creating a firm attachment along the whole length of the sealed area, which had a positive effect during the execution of tests. The production of samples requires a certain amount of skill; however, the most fundamental requirement is the use of a suitable means of separation with regard to the necessity of removing the temporary spacers whose only role is to ensure the sealant has the correct geometry [7].

It needs to be emphasized that the technical procedures for the application of the individual sealants prescribed by their manufacturer must be obeyed during the production of the test specimens. This mainly includes the proper cleaning of the base and the use of the required penetration coating. The sealed steel substructure is without surface treatment, i.e. it is a surface prone to rapid corrosion which without cleaning would become an excellent separation agent leading to rapid cohesive bond failure.

C. Test procedures

For every test and every type of sealant, 3 test specimens are prepared. The essence of the tests is either a single extension to a pre-defined value which is maintained for a certain period, or a certain number of cycles with alternating extension and compression. For the whole period of the test, the occurrence of adhesive and cohesive bond failures is monitored. The evaluated sealant is satisfactory if no failure occurs in any of the tested elements.

1) Determination of tensile properties during maintained extension

Before testing, the test samples are stored at a temperature of 296.15 ± 2 K and a relative humidity of 50 ± 5 % for a period of at least 28 days until the sealant has fully matured. Afterwards, they are subjected to 3 storage cycles: 3 days in a drying room at a temperature of 343.15 ± 2 K, 1 day in distilled water at 296.15 ± 2 K, 2 days in a drying room at 343.15 ± 2 K, 1 day in distilled water at 296.15 ± 2 K. The test itself takes place repeatedly at 2 different temperatures.

The test samples are inserted into a testing mould and are extended at a temperature of 296.15 ± 2 K at a speed of 5.5 ± 0.7 mm/min⁻¹ by 60 % of the original width of the sealant, i.e. from 12 mm to 19.2 mm. This extension is maintained at a temperature of 296.15 ± 2 K for a period of 24 hours. Any adhesive or cohesive failures are recorded with an accuracy of 0.5 mm [8].

Further tests take place at a decreased temperature. First, the test specimens are stored for at least 4 hours at a temperature of 253.15 ± 2 K. The rest of the procedure is identical to the previous one but the extension takes place and is maintained at a temperature of 253.15 ± 2 K. The recording of failures is carried out after the test specimens have been removed from the cooling chamber and defrosted [8].

2) Determination of the tensile properties of sealants at maintained extension after immersion in water

Before the tests are carried out, the test specimens are stored for a curing period of at least 28 days in the same way as in section C.1. This is followed by 3 weeks of cycles of alternating storage in distilled water and a drying room. Subsequently, the samples are immersed in a container of water at a temperature of 296.15 ± 2 K for a period of 5 days. After their removal from the water, they are stored exposed to the air for a period of 24 hours at a temperature of 296.15 ± 2 K and a relative humidity of 50 ± 5 %. The test itself takes place in the same way as in section C.1 via extension at a speed of 5.5 ± 0.7 mm/min⁻¹ by 60 % of the original width of the sealant, and the maintenance of this extension at a temperature of 296.15 ± 2 K for a period of 24 hours. Any adhesive or cohesive failures are recorded with an accuracy of 0.5 mm [9].

3) Determination of the adhesive and cohesive properties of sealants at variable temperatures

Before testing, the test specimens are stored in the same way as in section C.1 for a curing period of at least 28 days, followed by 3 weeks of cycles of alternating storage in distilled water and a drying room. Afterwards, the samples are subjected to 2 cycles of alternating extension and compression to an

amplitude of $\pm 20\%$ of the original width of the sealant as described in the following sections.

a) *Day 1:* The samples are placed into a cooling chamber at a temperature of 253.15 ± 2 K and, after 3 hours, extended by 20 % of the original width of the sealant, i.e. from 12 mm to 14.4 mm. The extension is maintained at a temperature of 253.15 ± 2 K for a period of 21 hours.

b) *Day 2:* The samples are removed from the cooling chamber, the extension is released and the test specimens are inserted into a drying room at a temperature of 343.15 ± 2 K. After 3 hours, the samples are compressed by 20 % of the original width of the sealant, i.e. from 12 mm to 9.6 mm. The compression is maintained for a period of 21 hours at a temperature of 343.15 ± 2 K.

c) *Day 3:* The compression is released and the procedure from day 1 is repeated.

d) *Day 4:* The extension is released and the procedure from day 2 is repeated.

e) *Day 5 – 7:* The compression is released and the samples are stored at a temperature of 296.15 ± 2 K and a relative humidity of $50 \pm 5\%$ without the use of mechanical force.

After the end of the tests, the test samples are examined and checked for the occurrence of failures. Any adhesive and cohesive failures are recorded with an accuracy of 0.5 mm [10].

4) *Determination of adhesive/cohesive properties of sealants at constant temperature*

Before the testing, the test samples are first stored at a temperature of 296.15 ± 2 K and a relative humidity of $50 \pm 5\%$ for a period of at least 28 days until the sealant has fully cured. Afterwards, the samples are subjected to storage in a drying room for a period of 14 days at 343.15 ± 2 K and then for 1 day at 296.15 ± 2 K and a relative humidity of $50 \pm 5\%$. The test itself then takes place at a temperature of 296.15 ± 2 K in the form of cycles of alternating extension and compression at an amplitude of $\pm 12.5\%$ of the original width of the sealant. The prescribed number of cycles is at least 100, at a speed of 1 mm/min^{-1} . After the end of the tests, the test samples are examined and checked for the occurrence of failures. Possible adhesive or cohesive failures are recorded with an accuracy of 0.5 mm [11].

IV. RESULTS

Table II summarizes the results of the recorded adhesive and cohesive failures for all the evaluated types of sealants arranged according to the individual testing procedures. The results are represented by the number of unsatisfactory samples, i.e. those for which any failure was found; the maximum value is 3.

TABLE II. RESULTS OF TESTS ON SEALANTS

Marking of sealant	Number of samples for which failures occurred during testing according to EN ISO				
	EN ISO 8340		EN ISO 10590	EN ISO 9047	EN ISO 9046
	296.15 ± 2 K	253.15 ± 2 K			
SO-U	1	3	2	2	0
SO-N	3	3	3	3	0
SO-PU	0	0	0	0	0
SO-MS	0	0	1	0	0
LU-U	1	1	2	2	0
LU-N	1	3	0	1	0
SL-U	1	1	1	0	0
SL-N	1	0	0	0	0
SL-PU	2	3	3	0	0
SL-MS	3	1	2	0	1

V. ANALYSIS

It is obvious from the test results that the number of adhesive and cohesive failures affecting the selected sealants on a steel substructure increases in connection with the magnitude of extension during testing. A great number of failures occurred during maintained extension by 60 % of the sealant width, regardless of the procedure by which samples were stored before the testing itself. In contrast, cyclic alternation of extension and compression resulted in lower failure rates, which is evidently due to the smaller amplitude. For the purpose of comparing the properties of sealants, a greater maintained extension magnitude is generally more beneficial.

As far as specific results are concerned, it can be stated that only 2 sealants are satisfactory when only evaluating maintained extension according to [8]. In the case of maintained extension after storage in water according to [9], 3 sealants are already satisfactory, and in the case of cyclic loading using alternating extension and compression at various temperatures according to [10], 6 sealants are already adequate. The cyclic loading test with a small amplitude as specified in [11] wasn't beneficial for the search for differences between individual sealants as almost all of them were satisfactory and successfully underwent the tests without problems.

VI. CONCLUSION

On the basis of the results of the measurements, a steel substructure without surface treatment can be considered sealable as at least one suitable product was found among a total of 10 evaluated products. It is polyurethane sealant 25D manufactured by Soudal, which was the only one that succeeded in all the tests without suffering any failure. Two other sealants were very close to success: MS polymer Soudal Soudaseal 215LM and neutral Silco, which only suffered one failure.

It is obvious that 3 test specimens constitute the absolute minimum for one test, but when the series of tests is evaluated

as a whole, i.e. 3 measurements for 5 different tests, one now has a set of 15 measurements which the sealant would have to pass without a single failure in order to obtain a positive evaluation. A greater number of tested samples would only mean a higher probability of a different type of failure, and thus an overall failure. However, the purpose of these tests isn't to eliminate all the evaluated sealants but to find the differences between them. This means identifying those which are more likely to be able to seal joints reliably. This aim can be considered to have been fulfilled.

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