

Failures in bituminous joint-sealing in concrete pavements

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Abstract

In many countries, e.g. Germany, concrete pavements are constructed with plain concrete (JPCP). In such constructions, joints and their sealing are essential elements for a durable longterm behavior. Recently, numerous damages in the joint sealants were detected as early as one to three years after application. Especially delamination of the sealant from the joint edges and tearing of the sealant itself have been observed. In former times none of such phenomena have been known, it is assumed that the bitumen quality had been modified over time. However, the material itself had fulfilled all requirements of the standard specifications. Therefore, also other components of the joint sealing like the adhesion layer or the saw cut resp. the roughness of the joint edges have to be considered as potential causes for the failure. Currently the single components are being tested separately. Thus, a comprehensive test method had to be developed which captures the behavior of the entire sealant system. Herewith, the adhesion layer as well as the surface in the joint edges can be evaluated under the relevant loadings. This had been developed within an extensive research project. In this test, the behavior of the entire joint system can be analyzed under static as well as under cyclic loads. Through this complete technical assessment, it will be possible to design and execute joint sealants in concrete pavements more durable.

Introduction

Defect joint sealings in concrete pavements impair their durability enormously. The penetration of surface water and other pollutants into the joints and subsequently into the substructure would cause offsets of the plates, edge damages and has to be prevented thus. Furthermore the risk of alkali silica reaction especially in the joint areas would be increased by penetrating of deicing agents solutions.

In the last few years numerous damages in joint sealants were detected in German pavements already one to three years after application. The detected deficiencies are mostly related to hot applied bituminous joint sealants. Characteristic for these damages is that they are found in replaced joint sealants as well as in joints of new concrete pavements. Furthermore these damages can be observed likewise in sections with and without traffic loads. In many cases they appear within the first three years after application of the joint sealant.

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As potential causes changes in the raw materials of the sealants, modified concretes as well as altered execution methods for joints are considered.

In the actual technical guidelines for joint sealants the testing of the functionality only regards to the separate components of the sealing. A comprehensive survey of the entire system (concrete, joint edge, primer and joint sealant) has not been practiced yet. Also not all significant stresses are simulated close to the reality in the laboratory tests.

In order to develop an appropriate test method, first the causes of the current problems must be detected. For this purpose the relevant influencing factors and stresses on a joint system must be elicited.

Joint movement

For the stress of joint systems the movements of joints during service and time are decisive. For that on one hand daily / seasonally temperature changes as well as shrinkage deformations are responsible. Because the latter have subsided after a few years, they are subordinated for the continuous joint movements.

For the relevant thermal deformations, on the one hand the temperature changes and on the other hand, the lengths of the concrete slab adjacent to the joint are crucial. The joint movement of concrete slabs is calculated as follows (Eisenmann 2003):

$$\Delta L = \alpha_T * \Delta T * L$$

α_T $1,2 * 10^{-5} [K^{-1}]$

ΔT Temperature change [K]

L Length of the concrete slab [m]

It can be assumed that in Germany concrete slabs heat up during the summer season due to the solar radiation up to about 45 °C, also when the air temperature is only about 35 °C. On the other side in winter temperatures of -15 °C can occur. So temperature changes of 60 K have to be considered as relevant for deformations within the joint sealants. For the subsequent stresses of the joint system the temperature at the application of the joint sealant (fixing temperature) plays a decisive role. Figure 1 shows the expansions and compressions of joint sealants generating from the joint movement at different application temperatures. The Figure is based on concrete slabs with a length of 5 m and a joint gap width of 8 mm.

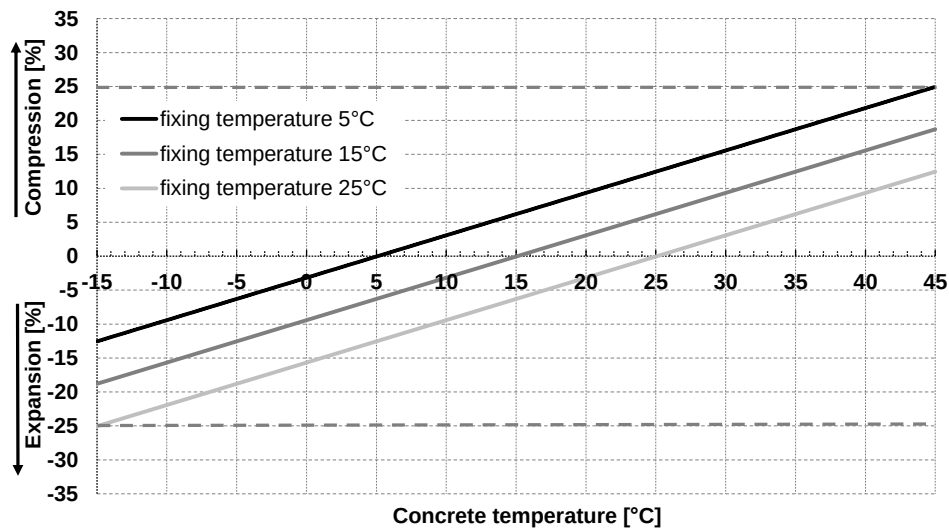


Figure 1: Expansions and compressions of joint sealants depending on the fixing temperature for 5 m long concrete slabs and a joint width of 8 mm

If the joint sealant is fixed at a low temperature, it will be stretched only slightly, because the temperature cools only slightly. In the opposite case, when the joint is fixed at a high temperature, the joint sealing will be compressed only slightly, because the temperature heats up only slightly as well. In this case, large expansions has to be expected in the wintertime.

In accordance with the valid standards, typical joint sealants for use in concrete pavements (type N2) are designed for changes to the joint width of up to 25 %. In Figure 1 it is also shown that this limit could be reached with a fixing temperature of 25°C and a cooling in the winter down to -15°C. Considering additional shrinkage deformations within a few years with strains up to 20% in the sealant, the limit value will be exceeded in many cases.

Compressions in the joint systems can only be set as far as the crack below the joint is closed. Also in this case the temperature at the joint cutting influences is relevant (Figure 2). These explanations shows that expansions are much more critical to evaluate as compressions.

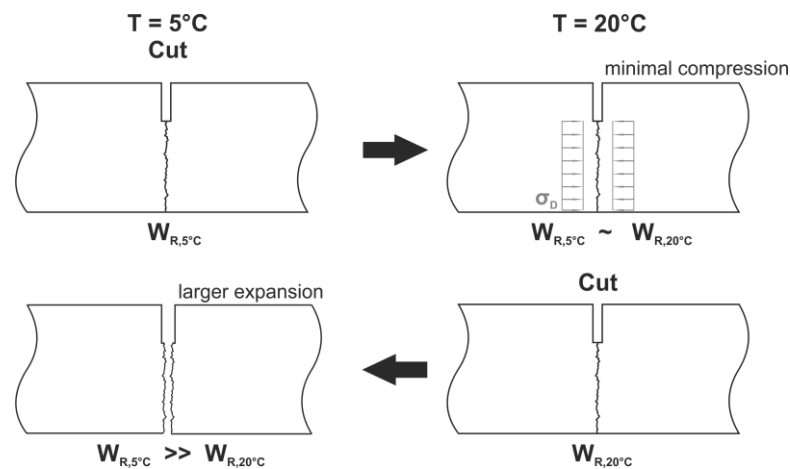


Figure 2: Influence of the temperature at the time of breakage by the slab to the joint movements

In the previous observation, a typical slab length of 5 m has been provided. This presupposes that each saw cut joint is actually cracked. However, if several individual fields are not consecutively cracked, they act as a total “package”. The much larger deformation then acts on the joint at the end of this package. The effect of such a “package cracking” on the relative joint deformations is illustrated in Figure 3. It can be seen that the deformation limit of 25 % has been already exceeded within a two-slab-package at a cooling rate of approximately 20 K.

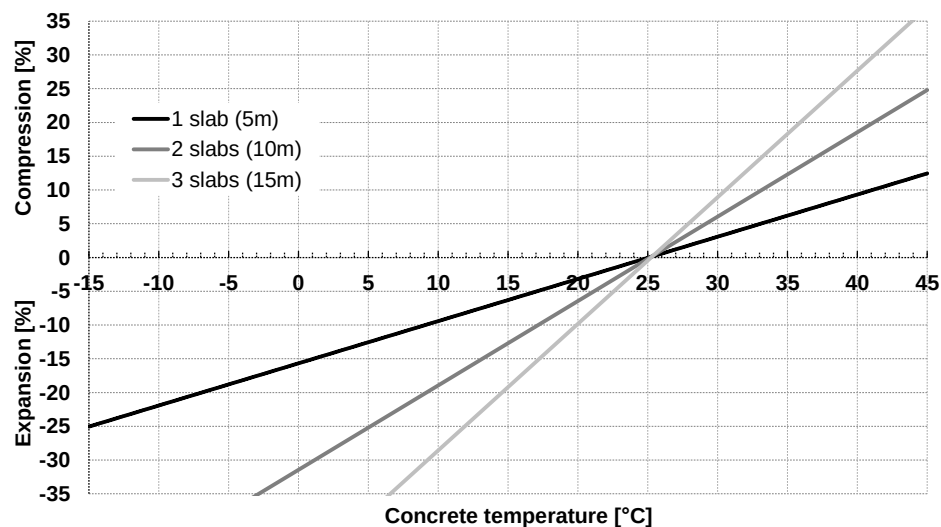


Figure 3: Expansions and compressions of joint sealings depending on non-rippled saw cut joints for 5 m long concrete slabs and a joint width of 8 mm

The horizontal joint movement due to temperature change has to be superimposed with vertical movements due to traffic loads. Depending on the subbase stiffness, the effectiveness of the aggregate interlock in the lower cracked joint section and that of the dowels, vertical displacements of less than 1 mm can be assumed. Thus due to the high-frequency cyclic traffics additional stresses on the joint system can arise.

Aging of the joint sealants

Besides the stresses due to joint movement, climatic influences affect the joint systems significantly. High temperature and UV-radiation lead to physical and chemical changes in the bituminous joint sealants. As a consequence, the material tends to be more viscous and the surface gets a brittle structure (Figure 4).

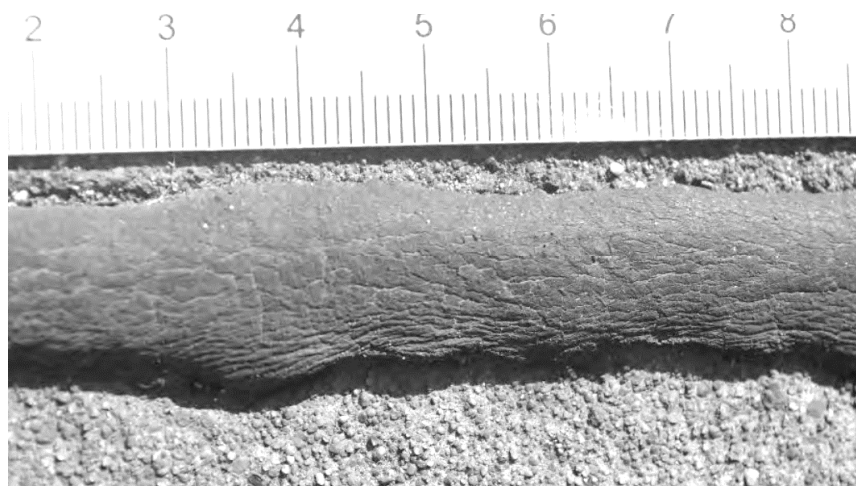


Figure 4: surface of a joint sealant with a brittle structure (after about 2 years)

Laboratory investigations

Investigations on bonding properties To investigate the behavior of joint sealants within the complete system concrete joint edge, adhesion layer and sealant material specimens as illustrated in Figure 5 have been developed.

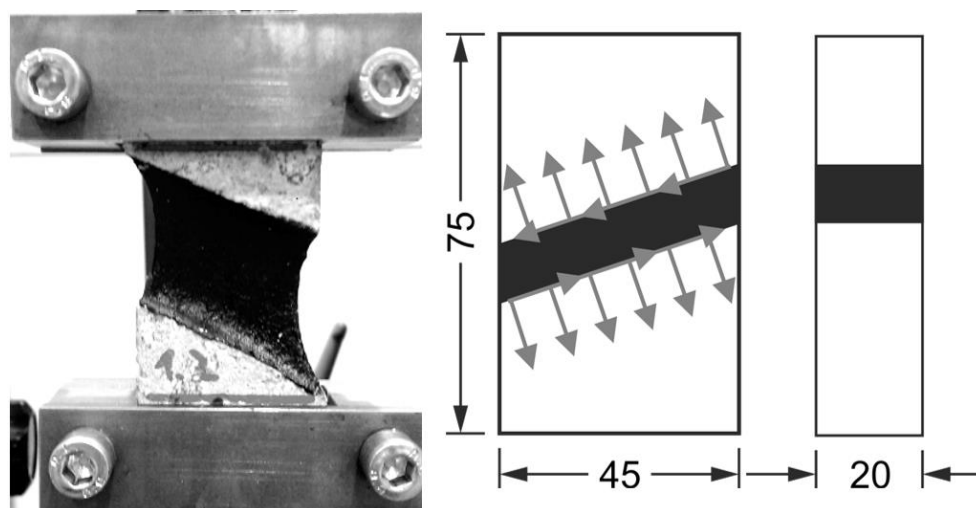


Figure 5: System specimen: left: tensile test; right: dimensions

In order to investigate horizontal as well as vertical joint movements in the same test, the joint is more or less inclined with respect to ratio between the two stress directions. Thus with this test device tension and compression as well as shear stresses in the sealant can be simulated within the same test. The (small) dimensions of these specimens have the advantage that such can also be gained by cores taken from existing concrete pavements.

In such tests the behavior of joint sealants was analyzed with several load histories, i.e. different deformation rates had been applied considering that those are varying widely in situ due temperature changes and traffic loads as well as. Also different temperatures have been implied as the rheological properties of the joint

sealant mainly are influenced by such. Figure 6 illustrates the stresses of four different joint sealing materials, all based on bitumen, which developed during such combined tensile-/shear tests. The test temperature was +20°C and the deformation rate was 1 mm/min. As can be seen, the maximum stress is approximately 0.02 MPa. In contrast to the others joint sealant FM3 had an adhesive failure at an expansion of approximately 25%. The other specimens failed by a loss in cohesion at very high deformations. In all cases the current required minimum expansion strain of 25 % had been achieved and exceeded resp.

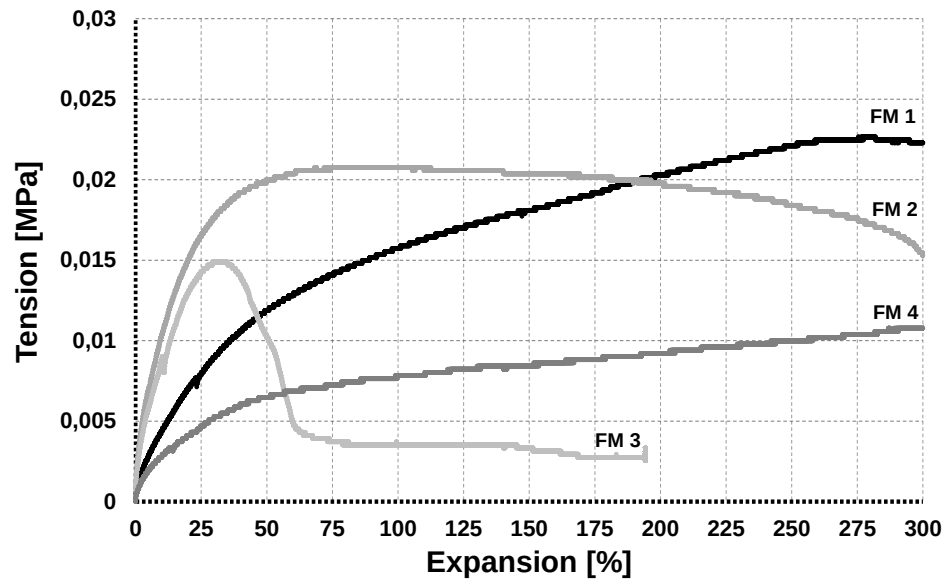


Figure 6: stresses of four joint sealant during a combined tensile-shear-test (+20°C / 1 mm/min)

Next the same test was performed, however, at a temperature of -20°C and a deformation rate of 0.1 mm/min (Figure 7). The maximum stress under these conditions was significantly higher (0.8 MPa). At this temperature, the bituminous material is quite more elastic, so that the stresses cannot relax as quickly as at + 20°C.

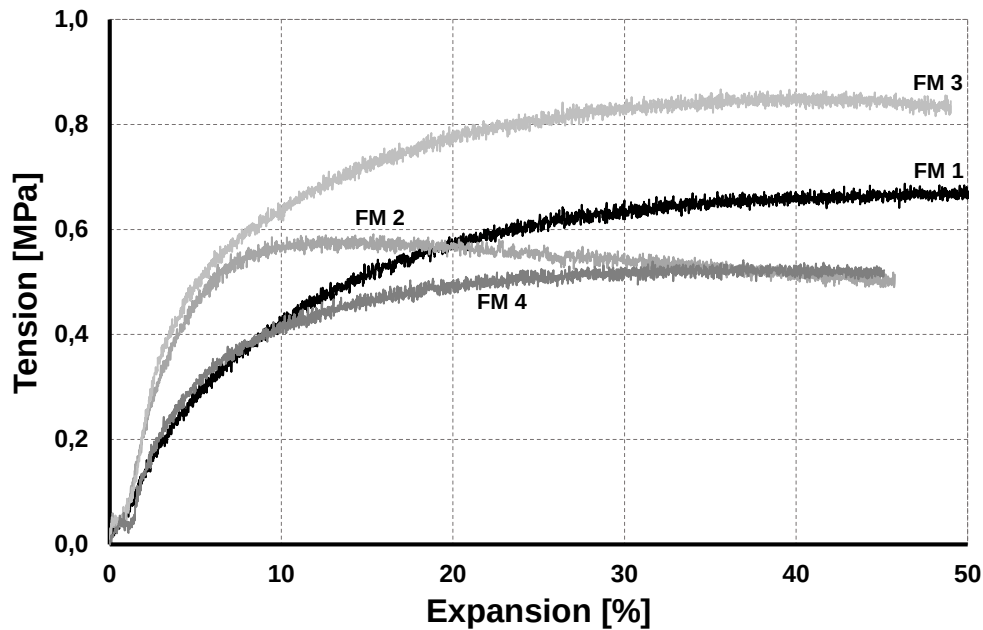


Figure 7: stresses of four joint sealant during a static tensile and shear test
(-20°C / 0.1 mm/min)

Rheological investigations on the joint sealant Besides these combined stress-shear-tests special investigations on the elastic and plastic behavior of the bituminous materials were conducted. For this purpose the complex shear modulus as well as the delay angle had been determined by a Dynamic Shear Rheometer (DSR) according to EN 14770. Additionally the relaxation behavior of these materials was studied by stretching a 5 mm thick bituminous film at 20°C to 10% and investigating the stress relaxation within 120 minutes (Figure 8). In these tests bitumen FM4 showed a quite different behavior related to the three other materials. The relaxation capacity of FM 4 was much higher than that of FM 1 to FM 3.

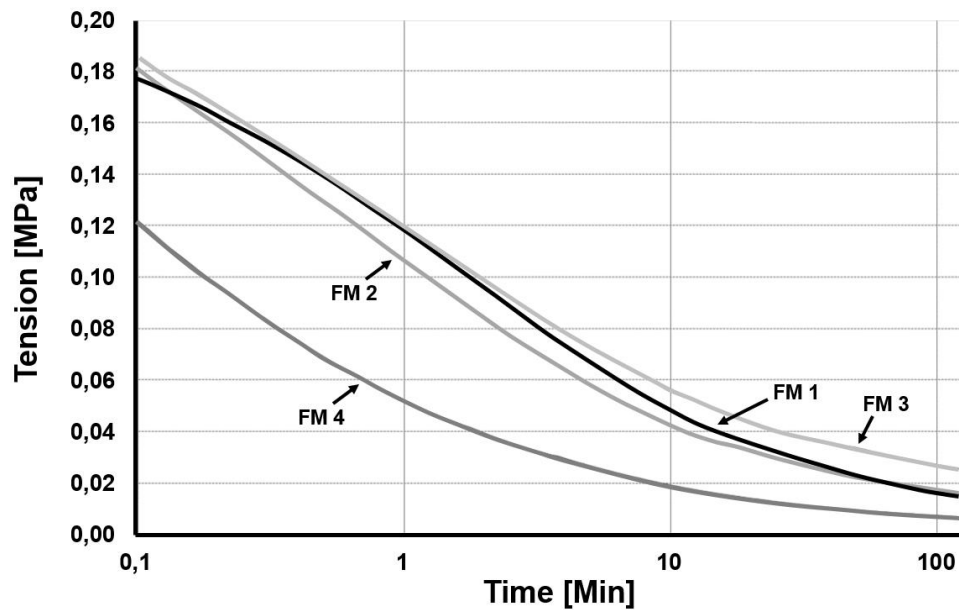


Figure 8: Relaxation behavior of four joint sealants

Investigations on aging of the joint sealant by freeze-thaw-cycles To examine the impact of freeze and de-icing agents on the joint system, specimen as illustrated in Figure 5 were exposed to freeze/thaw-attack based on a modified CDF-test in advance (Setzer 2006). After a defined number of freeze-thaw-cycles between -20°C and $+20^{\circ}\text{C}$, where also de-icing agents were introduced, the stresses of the bituminous joint sealants were determined in the a.m. combined tensile-shear-test at $+20^{\circ}\text{C}$. It could be proved, that by the precursory freeze-thaw attack the stresses are somewhat lower than those in a reference specimen without such a preloading (Figure 9).

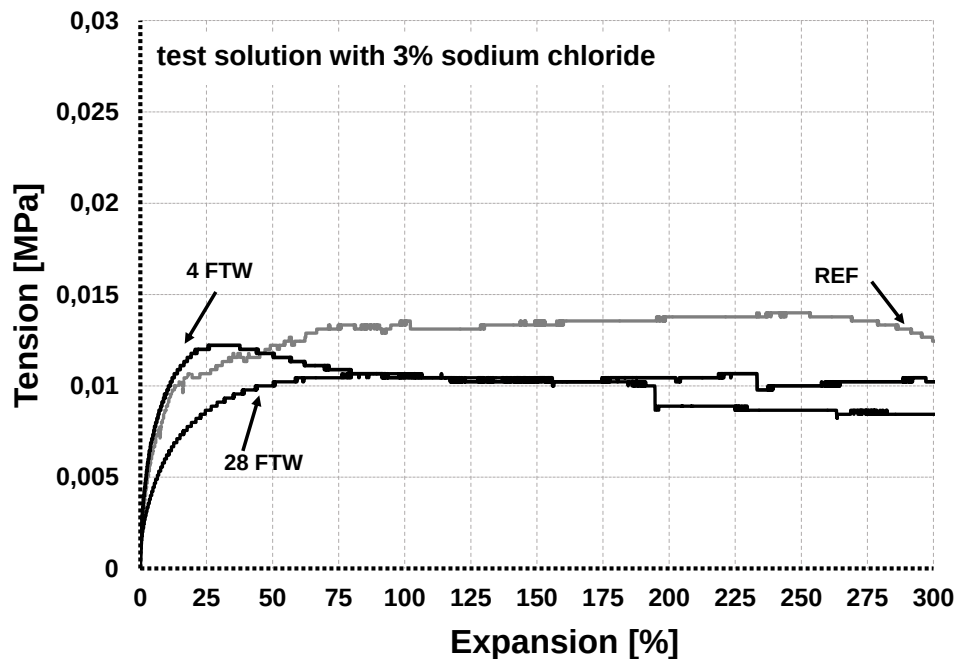


Figure 9: stresses of joint sealant during a static tensile and shear test after freeze/thaw-attack (+20°C / 1 mm/min)

Summary and further studies

To design and execute joint sealants in concrete pavements more durable in the future, it is necessary to investigate the whole joint-system with all relevant parameters. The joint-system is not only stressed by joint movement due to temperature changes, but also due to climatic influences which affect also the materials properties. A holistic “joint-system” test procedure has been developed in a extensive research project. First tests with variations in temperatures and deformation rates had been performed already. However, for a general evaluation further studies especially considering influences due to cyclic traffic loads with high frequency as well as aging effects have to be performed in the next future.

To simulate cyclic movements due to temperature changes over a year and within a day as well as traffic loads, a multiple test device is now under construction. With this device the specimen according Figure 5 can be stressed cyclically with varying frequencies from 5×10^{-5} up to 5 Hz. Also the temperature can be varied from -20°C up to +60°C within the same test.

The aging of joint sealants depends strongly on the ambient temperature and the intensity of solar radiation. To investigate the influence of temperature to the rheological characteristics of joint sealants, the bituminous material is exposed to an accelerated temperature aging based on a PAV-conditioning (Pressure Ageing Vessel). Thus, the aging of a joint sealant over several years will be simulated.

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