Accelerated Laboratory Evaluation of Joint Sealants Under Cyclic Loads

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Abstract

The sealing of joints and cracks in pavement structures has been in practice since the early 1900s. The optimized selection of joint sealant products can extend pavement service life and reduce annual maintenance and rehabilitation needs particularly in regions which experience extreme climatic conditions.

Early sealant materials were not subjected to standardized testing procedures and many failed as a result. Since then, several test procedures have been investigated and a few have been accepted into approved standards, such as the American Society for Testing and Materials (ASTM), for many of the materials on today's market. Variability within the sealants and the empirical nature of the tests have been ineffective in predicting sealant behaviour in the field. In addition, ASTM laboratory test procedures require long and sophisticated tests that many highway or transportation agencies are unable to perform, relying on past performance or previous field trials. This potentially leaves many newer and better performing sealants off the approved list of many agencies because of the lengthy and expensive process of field acceptance.

The purpose of this research was to investigate and rank the performance of eight hot pour joint and crack sealant materials for applicability of use in Manitoba through a performance-based lab testing approach. The project involves laboratory testing of sealant materials to verify fundamental properties and performance simulation under cyclic loading. Sealants were tested using a repeated compressive and tensile fatigue test at +30ºC, 0ºC and -30ºC.

The results of the laboratory tests indicated that Type I sealants exhibited higher initial load values and also experienced adhesion failure at both the 0°C and -30°C test temperatures. The Type IV sealants generally exhibited lower resistance to load and three of the eight sealants did not show signs of failure at any of the three test temperatures.

Introduction

The sealing of joints and cracks in pavement structures has been in practice since the early 1900s. Over the years, joint sealing materials have evolved from sand, tar paper, coal-tar pitch, asphaltic compounds, or wooden blocks to highly sophisticated materials such as silicones, polyurethanes, preformed, and hot-pour sealants in use today, (Lynch 1996). Early sealant materials were not subjected to standardized testing procedures and many failed as a result. Since then, several test procedures have been investigated and a few have been accepted into approved standards, such as ASTM, for many of the materials on today's market. However, variability within the sealants and the empirical nature of the tests have been ineffective in predicting sealant behaviour in the field.

The earliest documented material specification for hot-applied sealants was published in the 1940s, but was of limited value as the results were not reproducible, (Lynch, 1998). Since then, several test procedures have been investigated and a few have been accepted into an approved standard. ASTM standard D6690 is the approved standard for hot-pour sealants, (ASTM, 2001). ASTM laboratory test procedures require long and sophisticated tests that many highway or transportation agencies are unable to perform, relying on past performance or previous field trials. The current ASTM tests remain empirically-based and in the case of the bond or resilience tests show an "inconsistency of test results which leads to questions about the tests' validity", (Zanzotto, 1997). Furthermore, there is a lack of correlation between field and test conditions, as test results do not necessarily reflect field performance, (Masson, 2000).

This ASTM standard for hot-applied joint and crack sealants for use with concrete and asphalt pavements, classifies sealants into four types based on low-temperature extension performance. These sealants can be categorized into the four types listed below: (ASTM D6690)

- *Type I*—A joint and crack sealant capable of maintaining an effective seal in moderate climates. The material tested for low temperature performance at -18°C using 50 percent extension (formerly Specification D 1190).

- *Type II*—A joint and crack sealant capable of maintaining an effective seal in most climates. Material is tested for low temperature performance at -29°C using 50 percent extension (formerly Specification D 3405).
- *Type III*—A joint and crack sealant capable of maintaining an effective seal in most climates. Material is tested for low temperature performance at -29°C using 50 percent extension. Special tests are included (formerly Federal Spec SS-1401C).
- *Type IV*—A joint and crack sealant capable of maintaining an effective seal in climates experiencing very cold temperatures. Material is tested for low temperature performance at -29°C using 200 percent extension.

Purpose of Research

The purpose of this research was to investigate and rank the performance of various candidate sealant materials for applicability of use in Manitoba (which experiences very low winter temperatures) through a performance-based lab testing approach. The project involves laboratory testing of sealant materials to verify fundamental properties and performance simulation under cyclic loading.

The general objectives of this research project are to:

(a) Establish a performance-based laboratory test criteria and test methods at the University of Manitoba.
(b) Quantify and rank selected sealant materials using laboratory methods and field evaluation methods of bond and cohesion
(c) Provide Manitoba Transportation and Government Services, (MTGS), with a laboratory test procedure that successfully ranks sealant and correlates to field performance results.

Research Program

The research program included the evaluation of eight commercially available joint and crack sealants, eight hot-pour sealants that were submitted by five manufacturers. The eight hot-pour sealants selected for performance-based laboratory testing in this study fall under Type I and Type IV according to ASTM D6690. Under the current ASTM specifications, Type I sealants, are tested at -18°C using 50 percent extension for 5 cycles, while Type IV, low-modulus sealants, are tested at -29°C using 200 percent extension for 3 cycles. Table 1 lists the material properties of Type I sealants and Table 2 lists the material properties for Type IV sealants as per the technical data received from each manufacturer. The two Type I sealants are labelled as Sealant A and Sealant B while the six Type IV sealants are labelled Sealants C to F.

Each sample of sealant was sent to an accredited lab for ASTM verification testing by MTGS. The results of the verification ASTM testing are shown in Table 3.

Test Setup and Sample Preparation

From the research objectives the development of a performance-based test procedure for hot-poured sealants was laid out. Previous research conducted by Rogers (1998) and Al-Qadi (1999), have shown that fatigue testing of sealants is a better indication of sealants field performance. This research was to work with MTGS and develop a test methodology that can be carried out at a local laboratory.

Since a sealant that conforms to the current ASTM test methods will not necessarily perform well in the field (Lynch 1998), a cyclic loading test for local conditions was developed at the University of Manitoba for this project. The test applied repeated compressive and tensile loading cycles to compare sealant performance. While it is desirable to conduct accelerated thermal cycling rather than mechanical (load) cycling, it is deemed too slow and not practical to adopt in general laboratory use.

The repeated compressive and tensile loading test procedure was designed to provide an accelerated and performance-based laboratory testing method for hot-pour sealants. This procedure could be used by local transportation agencies wishing to test new materials without the need for lengthy field trials. This set up does not directly replicate a specified number of years in the field but provides a fatigue test to rank sealants against one another.

Sample Preparation

The sample preparation consists of the placement of a 10 mm strip of sealant between two concrete blocks and applying a predetermined cyclic displacement at three temperatures; +30°C, 0°C and -30°C. A schematic of the concrete block, sealant specimen and bearing plates set up is shown in Figure 1. The blocks were cast with four anchor bolts per end to connect to the loading frame. The aggregate used in the concrete was a mix of granite and river gravel, with a nominal aggregate size of 10 mm to allow the mix to flow around the bolts. The blocks, were allowed to cure after casting, until a minimum 28-day strength of 30 MPa was achieved. The blocks were saw-cut to simulate the surface of a typical concrete pavement joint. The sawn concrete blocks dimensions are 50 mm x 75 mm x 50 mm. The concrete blocks were washed and allowed to dry to minimize the debris left on the surface by the saw cut. The sealant was applied directly to the clean, dry surface. See Figures 2-7 for the setup of the test blocks.

Fatigue Testing

This test subjected the concrete blocks to plus and minus 2 mm tensile and compressive displacement while recording the load. The results have been analyzed to give the normal stress in KPa versus the number of cycles. The normal stress was calculated by dividing the load by the theoretical cross-sectional area of the sealant, which for each sample was 50 mm by 50 mm. The data acquisition machine was set to record 200 data points a second to capture the maximum and minimum results. The test was carried out at three in-service temperatures, +30ºC, 0ºC and -30ºC.

Fatigue Testing at +30ºC

The environmental chamber was equipped with a heater at +30°C to ensure that the test sample remained at the desired test temperature during the entire test. This chamber maintained the test temperature at +30ºC ± 1ºC. The samples were loaded using plus and minus 2 mm extension controlled loading at 1 Hz frequency for 25000 cycles completed in one work day. Two samples of each sealant were tested to confirm the test results. In cases where significant variation was found (>15%), a third sample was tested and the two closest results were retained.

Fatigue Testing at 0ºC

This test required the use of liquid nitrogen to lower the temperature to 0ºC. Each sealant was conditioned for up to one hour prior to the start of the test. The samples were loaded using plus and minus 2 mm extension controlled loading at 1 Hz frequency for 5000 cycles. The number of cycles was modified to run 5000 cycles as it was realized that more than 50 percent load drop had already occurred for all the samples.

Fatigue Testing at -30ºC

This test required the use of liquid nitrogen to lower the temperature to -30ºC. Each sealant was conditioned for up to one hour prior to the start of the test. The samples were loaded using plus and minus 2 mm extension controlled loading at 0.003 Hz frequency for a maximum of 25 cycles. The extension remained the same during all three test temperatures, but at -30ºC after a number of catastrophic failures of both the concrete and the sealant, the frequency and duration of the test were lowered to ensure results could be obtained for each sealant.

Fatigue Laboratory Performance and Test Results

The typical data for the load and stroke vs number of cycles for each sealant was recorded and is shown in Figure 8, with the displacement (stroke) form shown on the left y-axis and the load shown on the right y-axis. Due to the viscoelastic nature of the sealant materials, a phase lag was observed between load and displacement. These results are typical of all of the hot-pour sealants with variations occurring between the starting load values of the Type I and Type IV sealants.

Figure 9 displays an example of Sealant E, a Type IV sealant, hysteresis loops at +30ºC, which shows a linear stress versus strain relationship in compression and a non-linear relationship in tension. Type IV sealants exhibited lower initial stress values both in tension and compression than Type I sealants, resulting in longer lasting sealants. Figure 9 also shows the typical reduction in stress over the duration of the test. Initially at 50 cycles, the sealants were recording maximum stresses of -80 KPa in compression and 40 KPa in tension, by the end of 10000 cycles the stresses had dissipated to -40 KPa in compression and 20 KPa in tension. These are typical values of a Type IV sealant.

Figure 10, displays an example of the hysteresis loops at 0ºC for a Type I sealant, Sealant B. The stress values are considerable higher. The Type I sealants, consistently showed higher initial peak values as well as adhesion failure by the end of the test. These sealants did not perform well at 0ºC and would not be recommended for use in cooler climates. The resistance to load decreases as the number of cycles increases due to the onset of adhesion and cohesion damage.

Figure 11, displays the hysteresis results of Sealant H, a Type IV sealant at -30ºC. This sealant although not the best performing sealant, had only one sample fail in adhesion. The results for Sealant H were consistently lower than the results for the Type I sealants but not lower than Sealants D and E which were considered the two best performing sealants in the laboratory trials.

Figures 12 to 14 display the average initial stress values for each sealant at the three in-services temperatures. It is clear from the figures that the Type I sealants, sealants A and B consistently have larger initial stress values than the Type IV sealants. At +30ºC the Type I sealants display higher initial results than the Type IV sealants. At 0ºC sealants A, B and C display higher initial stress results and at -30ºC only sealants D and E maintain low initial stress values.

Conclusions

The results of the laboratory tests indicated that Type I sealants exhibited higher initial load values and also experienced adhesion failure at both the 0°C and -30°C test temperatures. The Type IV sealants generally exhibited lower resistance to load and three of the eight sealants did not show signs of failure at any of the three test temperatures.

Low modulus sealants are typically able to withstand larger extension. The accelerated testing compared sealants subjected to displacements similar to traffic and temperature loadings in the field. In general, and based on the limited number of sealant products tested, Type I sealants performed poorly when compared to Type IV sealants. Both Type

I sealants failed prematurely at the 0°C and -30°C temperatures as well three Type IV sealants failed prematurely at the -30°C test temperature.

The results show that the fatigue test can be used as a performance-based testing for successfully evaluating sealant performance in the lab. However the results of this study are preliminary and are based on a limited number of samples. The lab ranking must be correlated and verified with field performance data that used the eight sealants.

References

1. American Society for Testing and Materials. Annual Book of ASTM Standards. Vol. 04.03, American Society for Testing and Materials, Philadelphia, 2003.

2. Al-Qadi, I.L., S. Aboqudais, and R.E. Khuri. "A Method to Evaluate Rigid Pavement Joint Sealant Under Cyclic Shear and Constant Horizontal Deflections." Transportation Research Record No. 1680, TRB, National Research Council, Washington, D.C., 1999, pp. 30-35.

3. Lynch, L.N. Rheological Analysis of Silicone Pavement Joint Sealants. Technical Report GL-96-4, US Army Corps of Engineers, Waterways Experiment Station. February 1996.

4. Lynch, L.N. and D.J. Janssen. "Pavement Joint Sealant Specifications—Past, Present, and Future." Journal of Elastomers and Plastics. Vol. 30, April 1998, pp.161-181.

5. Masson, J-F. Bituminous Sealants for Pavement Joints and Cracks: Building the Basis for a Performance-Based Specification. Proceedings of the Third RILEM International Symposium. 2000, pp. 315-328.

6. Rogers, A.D., P. Lee-Sullivan and T. Bremner. "A Method of Fatigue Testing of Concrete Highway Joint Sealants in Shear". Journal of Testing and Evaluation. Vol. 26, No. 3. May 1998. pp. 234-239.

7. Zanzotto, L. Laboratory Testing of Crack Sealing Materials for Flexible Pavements. Transportation Association of Canada Research Report, 1997.

List of Tables and Figures

TABLE 1: Material Properties for Type I Sealants as per manufacturer's datasheets

Sealant	Penetration (1/10 mm)	Flow (mm)	Bond (at -18°C)	Resilience (%)	Asphalt compatibility	Max. heating temp. (°C)	Application temp. (°C)
A	80	nil	Pass	N/A[1]	N/A	N/A	185-200
B	100	3 Max.	Pass	30%	Pass	204	188-199
Specification limits	90 Max.	5 Max.	Pass 5 cycles @ 50% ext.	N/A	Pass	N/A	N/A

[1] N/A = not available

TABLE 2: Material Properties for Type IV Sealants as per manufacturer's datasheets

Sealant	Penetration (1/10 mm)	Flow (mm)	Bond (at -29°C)	Resilience (%)	Asphalt compatibility	Max. heating temp. (°C)	Application temp. (°C)
C	103	nil	Pass	80%	Pass	N/A[1]	185-200
D	100-150	10	Pass	30-60%	Pass	204	193-204
E	130	3	N/A	30%	Pass	204	188-198
F	120	1	Pass	70%	Pass	200	170
G	120	3	Pass	54%	Pass	200	170
H	100-150	10	Pass	30-60%	Pass	210	193
Specification limits	90-150	3 Max.	Pass 3 cycles @ 200% ext.	60% Min.	Pass	N/A	N/A

[1] N/A = not available

TABLE 3: Results of Verification Testing by MTGS for Material Properties Type I and IV Sealants

Sealant	Penetration (1/10 mm)	Flow (mm)	Bond (at -29°C)	Bond (at -18°C)	Resilience (%)	Oven Aged Resilience (%)	Asphalt compatibility
A	67	2	-	Pass	82	65	Pass
B	95	1	-	Pass	67	63	Pass
C	95	2	Pass	-	83	72	Pass
D	115	1	Pass	-	68	66	Pass
E	148	1	Pass	-	71	68	Pass
F	116	0	Pass	-	54	52	Pass
G	115	0	Pass	-	53	52	Pass
H	121	0	Pass	-	72	72	Pass

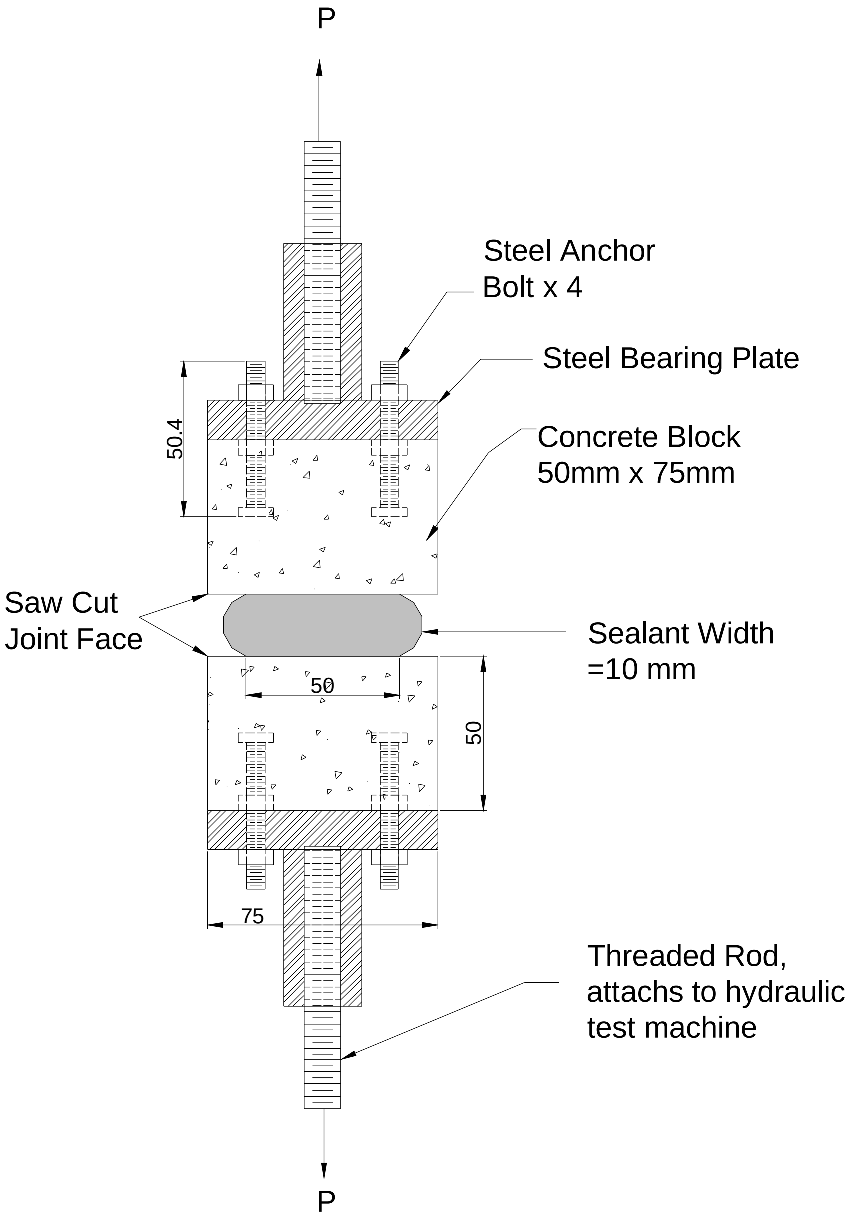

FIGURE 1: Concrete block, sealant specimen and bearing plates.

FIGURE 2: Formwork for concrete blocks with anchor bolts

FIGURE 3: Concrete blocks after pouring

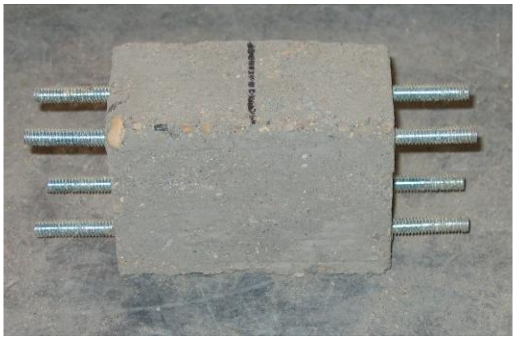

FIGURE 4: Concrete block prior to sawing, 100mm(w) x 75 mm (h) x 50 mm (d)

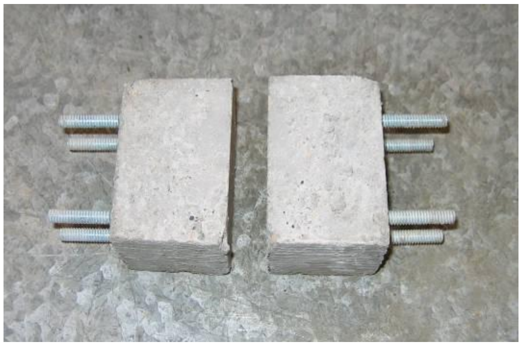

FIGURE 5: Sawn concrete block, 50mm(w) x 75 mm(h) x 50 mm(d)

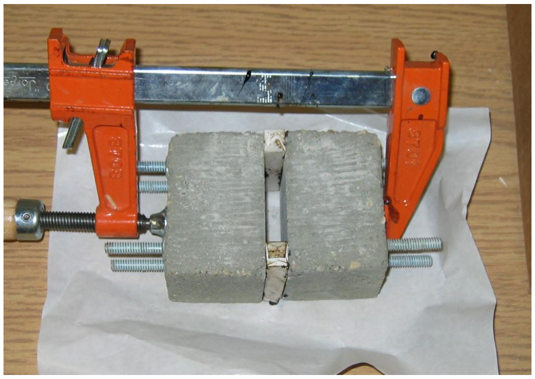

FIGURE 6: Spacers and clamp in place ready for sealant

FIGURE 7: Finished product, sealant trimmed and ready for testing

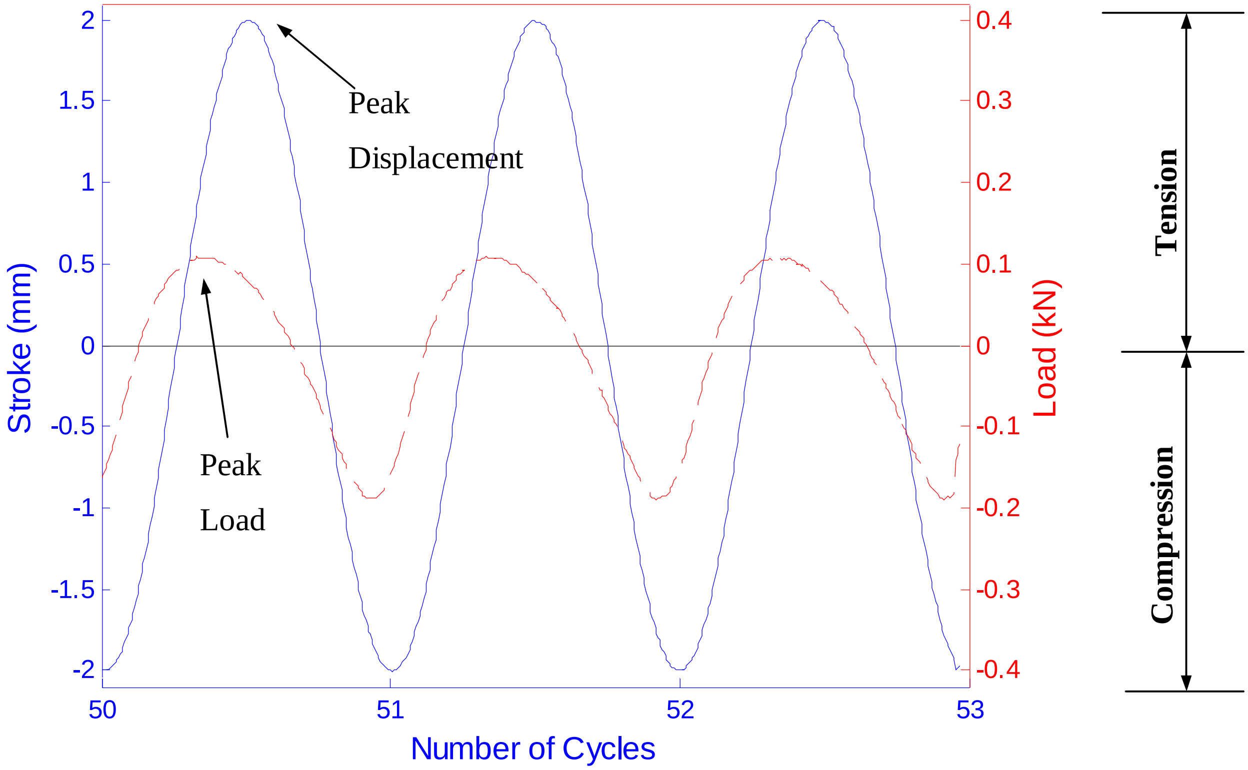

FIGURE 8: Typical load and stroke versus number of cycles conducted at 1Hz frequency.

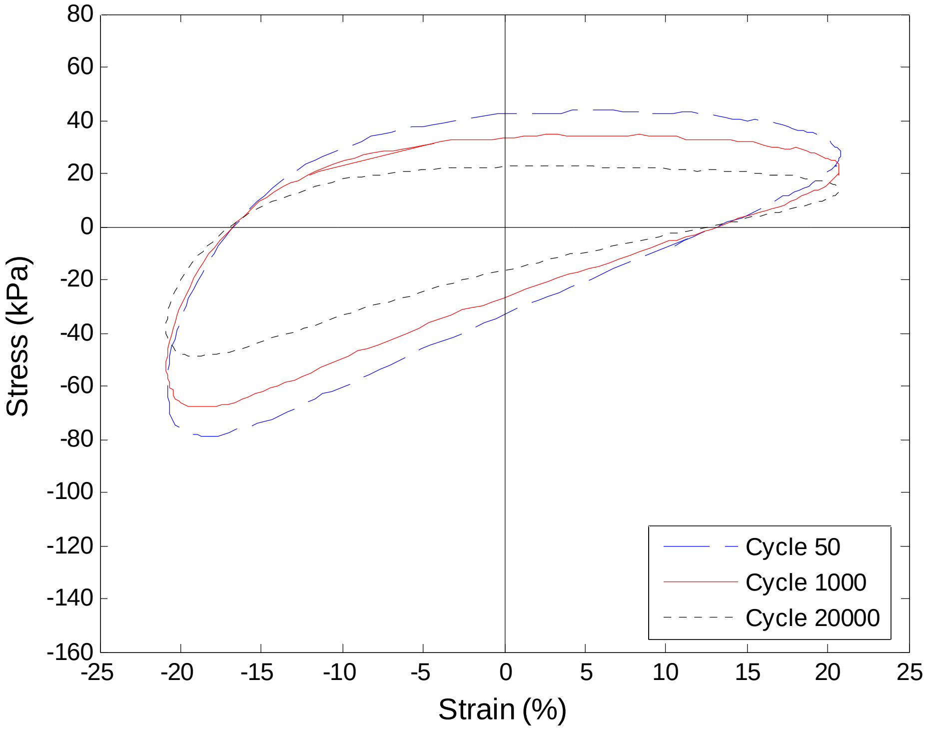

FIGURE 9: Sealant E Hysteresis Loops (+30°C)

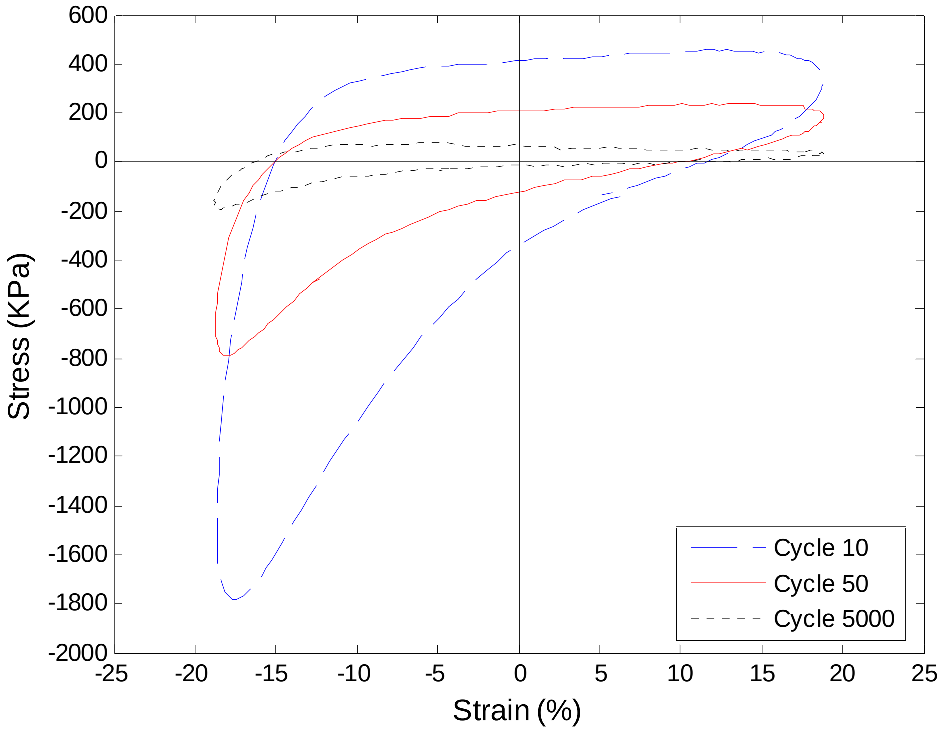

FIGURE 10: Sealant B Hysteresis Loops (0°C)

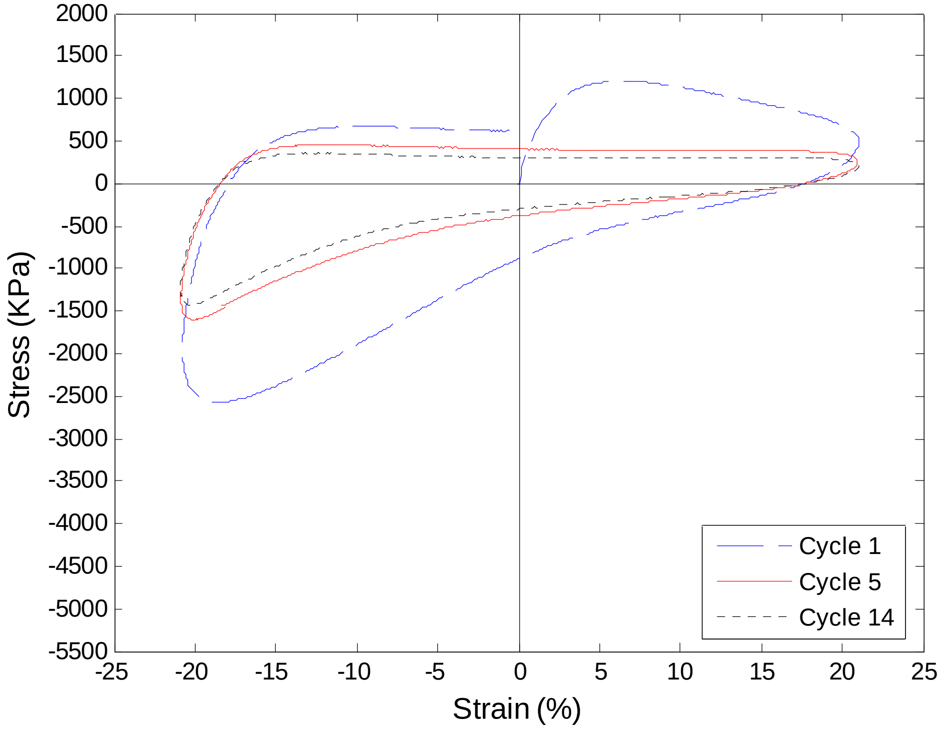

FIGURE 11: Sealant H Hysteresis Loops (-30°C)

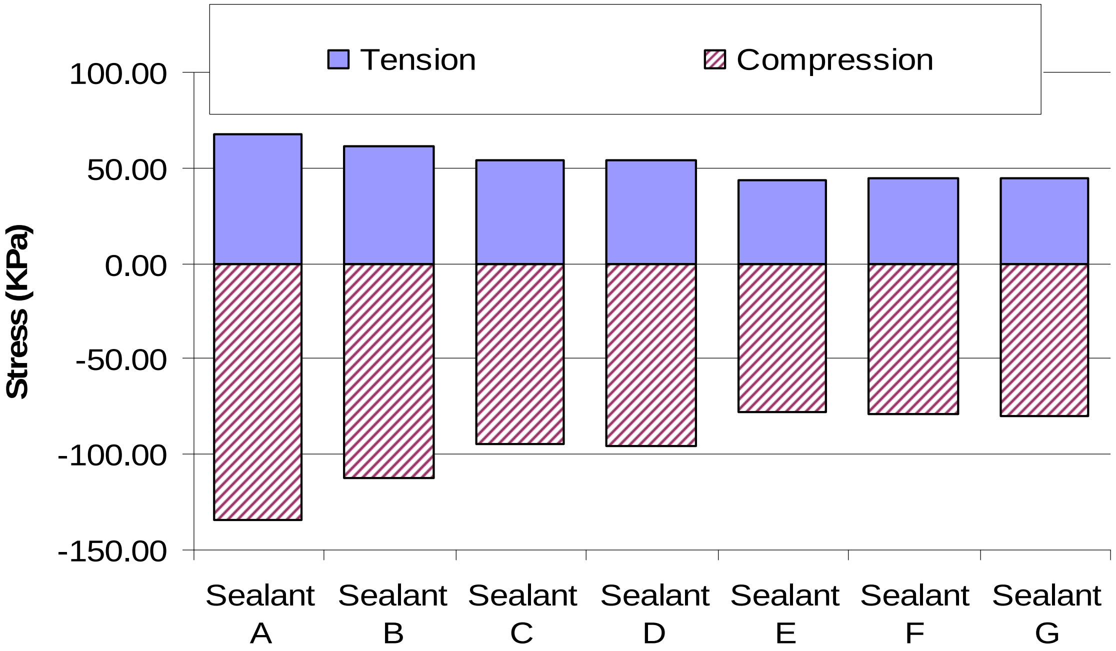

FIGURE 12: Average Initial Stress Values at +30°C

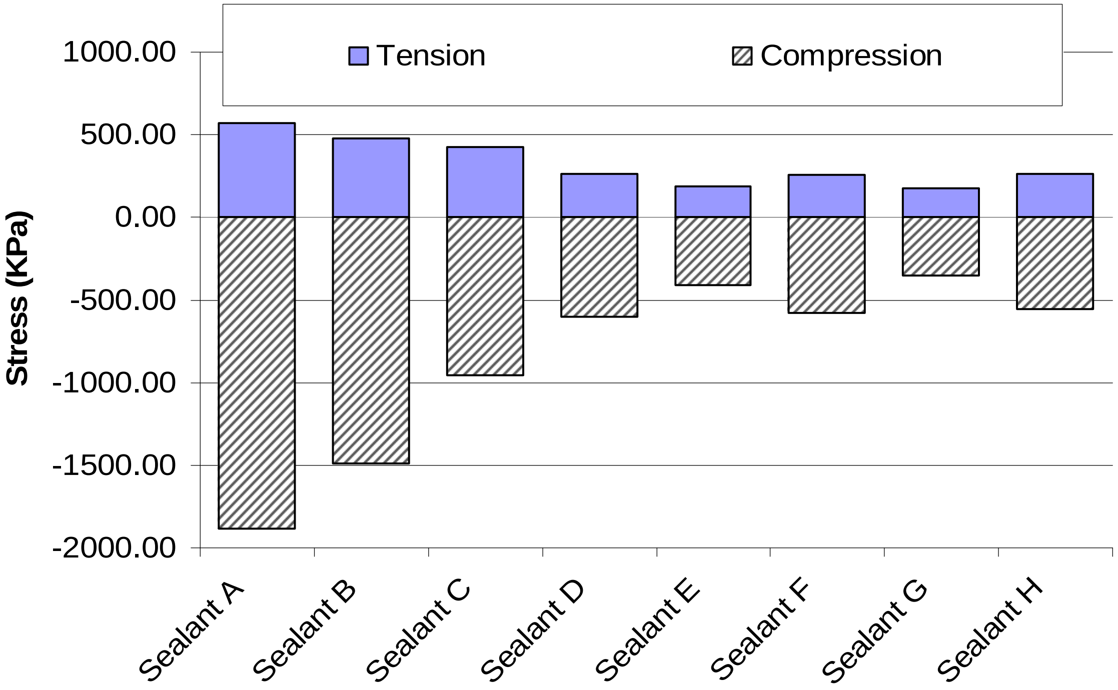

FIGURE 13: Average Initial Stress Values at 0°C

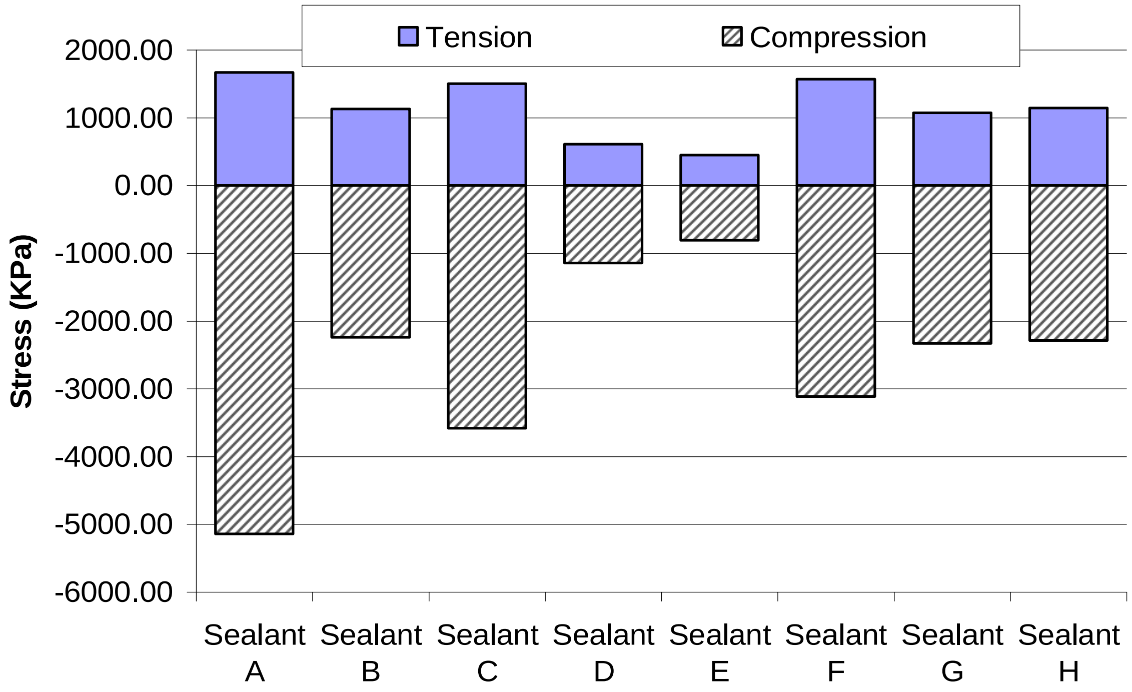

FIGURE 14: Average Initial Stress Values at -30°C