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TEMPERATURE CORRECTED TENSILE STRENGTHS FOR GEOMEMBRANE FIELD SEAMS

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ABSTRACT

Tensile testing of geomembrane seams is a fundamental aspect of the Quality Assurance plan on many installation projects. Qualification welds and cut-out coupons are sampled and tested in peel and shear modes on portable tensile testing machines (tensiometers) in a variety of weather conditions. Field testing is often performed at ambient temperatures with little or no conditioning prior to the test. Temperature correction charts are currently not available for the testing methods and geomembrane materials currently in use. Since thermoplastic geomembrane materials show a dramatic change in tensile properties with temperature, field test results can often appear to fall below project requirements. This study investigates temperature/tensile behaviour of commonly used geomembrane materials. Using both laboratory and field tests, a correction factor was found to adjust tensile strengths at break from ambient test temperature to standard test temperature. This correction factor can be used to calculate an immediate temperature corrected tensile strength at break, which can be used to estimate specification compliance of properly conditioned samples.

INTRODUCTION

In the last ten years the testing and Quality Control (QC) procedures used on geomembranes have undergone fundamental changes. Moving from strictly visual techniques to more quantifiable methods, one of the most dramatic changes has been the use of tensiometers in the field. Portable tensiometers are now relatively inexpensive, readily available, and are standard equipment with most geomembrane installers.

Portable tensiometers are used in the field by the installation contractor to rapidly estimate if the seam strengths prepared will meet the required project specifications. The results provided by an on-site portable field tensiometer allow the contractor to proceed with installation immediately without having to wait for specification conformance testing from an off-site laboratory. Using the results given by the field tensiometer, the contractor predicts whether the off-site conformance testing will be successful, and proceeds with installation based on this prediction. It is vital that the contractor accurately estimates whether the seam samples sent off-site will meet the job specifications so that costly seam cut-outs and repairs are avoided.

A fundamental problem with using portable tensiometers in the field is that it is difficult to maintain an accurate test temperature. There are different ways that contractors have attempted to control test temperature including climate controlled trailers, moving the tensiometer out of direct sunlight, using buildings or other site facilities, and even performing testing at the hotel where the crews are billeted. Generally, the larger the job, the easier it is to include facilities to control testing temperature. On some projects, however, the testing must take place at temperatures far from the ideal of +23°C. On these projects the contractor needs some way to compensate the observed test value to +23°C so that a prediction of specification conformance can be reached.

There are two situations when the accuracy of the portable tensiometer is most suspect. The first situation is in very hot weather. In elevated temperatures the tensile strength of the material decreases and minimum seam strengths may not be met on field equipment. Elevated test temperatures also increase the elongation of the material, often exceeding the stroke of the tensiometer. Low test results on warm days usually lead to the installer replacing seams that apparently do not meet specification. The second situation where accuracy may be compromised is in cold weather when material being tested may not meet a minimum tensile elongation requirement. Other cold weather problems that may contribute to an inaccurate result are; exceeding the tensile capacity of the load cell, and freezing the electronics of the tensiometer.

This paper investigates the feasibility of a temperature correction factor that may be applied by contractors to accurately predict the results of off-site specification conformance testing of field seams when field testing was performed at temperatures other than +23°C. This paper does not recommend the use of field testing performed at temperatures other than +23°C for final specification acceptance testing. Further testing would also be required to confirm whether the portable field tensiometers retain their accuracy at varying temperatures.

SCOPE

This study looked at the problems associated with variations in testing temperature when testing geomembranes with portable tensiometers. The goal of this study was to determine if there was a regular relationship between the tensile strengths at break of geomembrane materials and temperature, and to determine a "correction factor" that would allow extrapolation of field testing results to an approximation of standard laboratory temperature. The study took place in three phases. The first phase tested a number of materials to select candidates for further testing and to determine the testing limits of the available apparatus. The second phase of the study looked at three thicknesses each of PVC and HDPE and checked temperature vs. tensile strength at break for material and seam samples. The third and final phase of the study involved taking a portable tensiometer into a temperature controlled room and testing material and seam samples at extreme ambient conditions.

The tensile performance of thermoplastic materials has been well understood for many years. Simply put, as the temperature increases the tensile strength decreases. There is also a corresponding increase in tensile elongation as temperature increases. For most thermoplastic unsupported geomembrane materials the relationship between temperature and tensile strength is linear throughout the expected service temperatures. In a series of 500 tests on HDPE Giroud et al (1993) showed that the temperature versus tensile performance was a linear relationship between -20°C and +70°C. Richards et al (1985) showed that for PVC and HDPE the temperature versus tensile performance was linear between +23°C and -26°C.

The purpose of this study was to look at tensile strength at break under field testing conditions that varied in temperature and to see if a correction factor could be prepared that accurately predicted values at standard test temperature.

PHASE ONE TESTS

The first phase of testing was used to determine the capacities and testing capabilities of an available apparatus. Using a temperature conditioning chamber attached to a lab tensiometer, a series of tests were performed on HDPE, PVC, PP, and a proprietary PVC alloy material trade named Arctic Liner™. Table 1 lists the materials that were tested. All materials tested were unsupported thermoplastics. Figure 1 shows the general arrangement of the conditioning chamber. Solid and liquid CO_2 were used to reduce the temperature in the chamber while integral heaters were used for elevated temperature testing. The Instron conditioning chamber was mounted on an Instron Model 1123 tensiometer and all tests were recorded on chart paper. The apparatus had a restricted stroke of 450 mm (18") due to the size of the conditioning chamber which reduced available crosshead travel.

Phase one testing used a specimen width of 12 mm (0.5") in a "dog-bone" type specimen and tested in accordance with the American Society for Testing and Materials (ASTM) standard D638. A grip separation of 100 mm (4") was used. A temperature range of +60°C to -14°C was chosen based on the capabilities of the apparatus. Three specimens were tested of each sample.

Material	Thickness	Supplier
Flexible Polyvinyl Chloride (PVC)	0.5 mm, 0.75 mm, 1.0 mm	Nanya Plastics
High Density Polyethylene (HDPE)	1.0 mm, 1.5 mm, 2.0 mm	Columbia Geosystems
Flexible Polypropylene Alloy (PP)	0.5 mm, 0.75 mm, 1.0 mm	Layfield Plastics
PVC-Nitrile alloy (Arctic Liner™)	0.75 mm	Canadian General Tower

Table 1. Material Descriptions.

Figure 1. View of test apparatus showing conditioning chamber.

Figure 2 shows the tensile strength at break results from the first testing phase for 1.5 mm (60 mil) HDPE, 1.0 mm (40 mil) PVC and 0.75 mm (30 mil) Arctic Liner™ materials. Each of the materials shows a roughly linear relationship between tensile strength at break and temperature. Figure 3 shows the relationship between elongation and temperature for phase one. The restricted elongation available with the apparatus limited testing on a number of materials. Testing of PP was not successful due to the limited stroke of the apparatus which prevented testing to break.

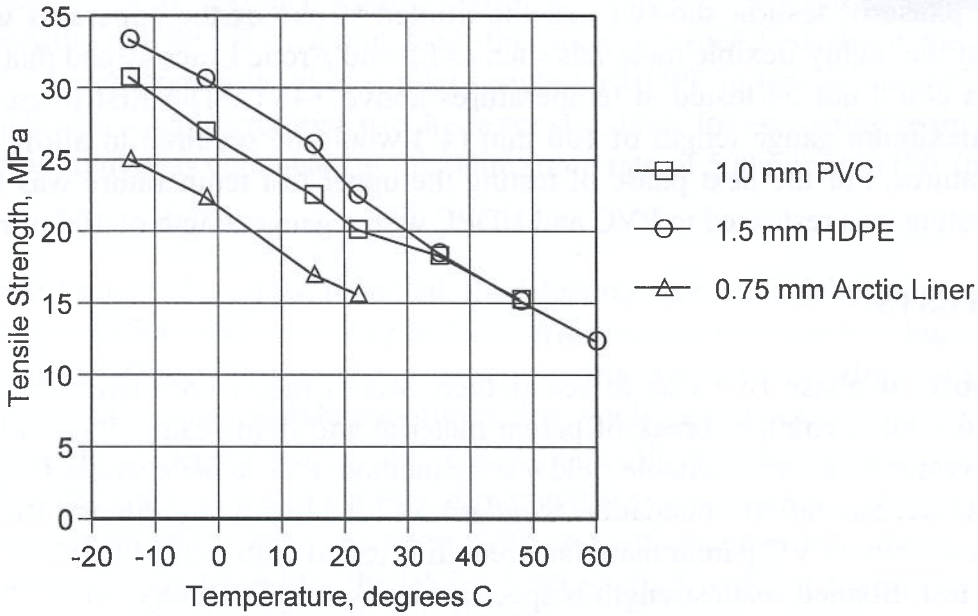

Figure 2. Phase 1 - Tensile Strength at Break vs. Temperature

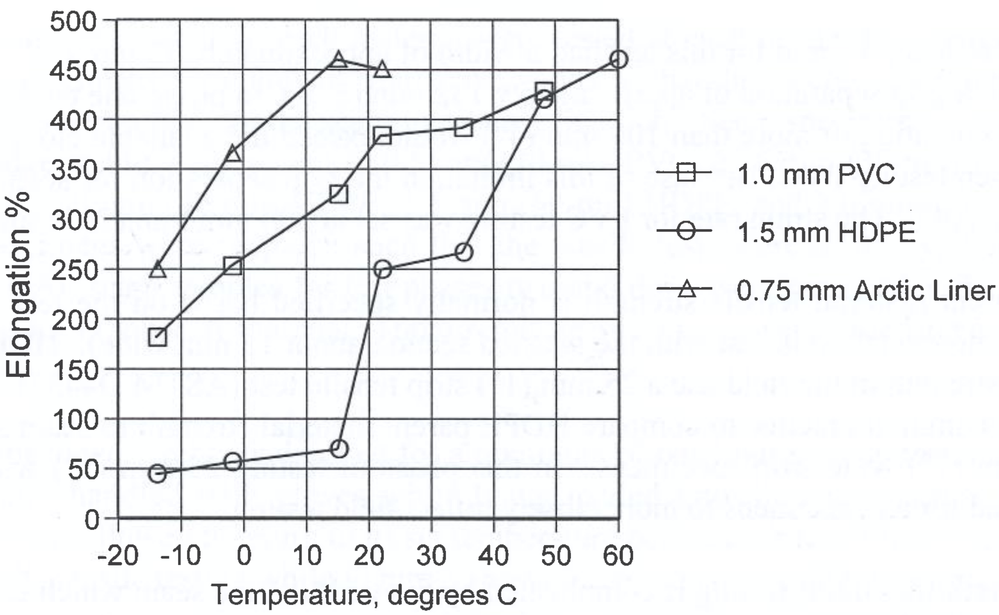

Figure 3. Phase 1 - Elongation at Break vs. Temperature

The results of the first phase showed that the temperature/tensile strength at break relationship for the geomembrane materials was approximately linear over the range of temperatures tested. Tensile test results appeared to be relatively consistent. Elongation test results appeared to have a strong trend towards linearity, however variation in the small sample size precluded direct conclusions on elongation properties. A more complete listing of the observations of this phase is contained in the unpublished student paper "Effects of Temperature on Tensile Properties of Liner Materials" by Jason Stang.

The first phase of testing showed that the limited stroke of the apparatus would not support testing of the highly flexible materials such as PP and Arctic Liner^{TM}, and that PVC and HDPE materials could not be tested at temperatures above +48°C. The first phase test also showed that a maximum gauge length of 100 mm (4") would be required to allow testing at elevated temperatures. For the next phase of testing the upper test temperature was limited to +48°C and the testing was restricted to PVC and HDPE with a gauge length of 100 mm (4").

PHASE TWO TESTS

The purpose of phase two was to see if there was a direct correlation between the temperature vs. tensile strength at break of parent material and field seams. Phase two testing began with an investigation into a suitable field testing method. PVC tensile strength is specified according to National Sanitation Foundation Standard 54 for Flexible Membrane Liners (NSF 54). NSF 54 specifies that PVC parent material strength is tested with ASTM D882, in a 25 mm (1") strip tensile test. Bonded seam strength is specified using ASTM D3083 with a 25 mm (1") wide specimen and a grip separation of 100 mm (4") plus the width of the seam.

The PVC seams prepared for this test had a width of approximately 32 mm (1.25"). This would have led to a grip separation of approximately 132 mm (5.2"). In phase one testing it was seen that a grip separation of more than 100 mm (4") would exceed the available elongation of the apparatus when testing PVC. Because of this limitation the grip separation for seam testing was set at 100 mm (4"). The strain rate for PVC testing was set at 500 mm/min (20"/min).

HDPE parent material tensile strength is normally specified based on the test method ASTM D638 (a "dogbone" style test with the waisted section about 12 mm wide). HDPE tests of bonded seam strength in the field use a 25 mm (1") strip tensile test (ASTM D4437). In field applications it is common practice to compare HDPE parent material strength to seam strength by testing 25 mm (1") wide strip specimens. In this phase of testing 25 mm (1") wide strip samples were used for all specimens to more closely reflect field testing.

Gauge length for HDPE testing is complicated by the width of the seam which can reach 50 mm (2") wide. To follow the requirements of NSF 54 requires a grip separation of 100mm ± 50 mm or 150 mm (6"). However, phase one testing showed that a gauge length over 100 mm (4") would not be possible to test on the available apparatus. For this phase of testing a 100 mm (4") grip separation was used for both parent material and seam specimens. An informal survey of HDPE installers in North America revealed that a 100 mm (4") gauge length is commonly used in seam testing in the field with portable tensiometers.

The last point of discussion was the strain rate. The strain rate for HDPE testing is normally specified at 50 mm/minute (2"/min), however field operations may increase the strain rate to 500 mm/minute to speed testing. Initially all samples had been tested at a strain rate of

500 mm/min (20"/min) and this strain rate was maintained throughout all testing phases for all materials. Although this is different from the normally specified strain rate of 50 mm/min (2"/min) the faster strain rate gives similar results for HDPE in tensile strength at break. Under certain conditions a contractor may use the faster strain rate for estimating seam compliance. All testing in this study was conducted at the same strain rate of 500 mm/min (20"/min).

Phase two of the study modeled field testing using the laboratory tensiometer and conditioning chamber to see if a temperature correction factor could be obtained for PVC and HDPE materials. Three temperatures were chosen for phase two testing; +48°C, +23°C , and -14°C. This met the range of field conditions that would be expected while keeping within the limitations of the test apparatus. Three thicknesses of PVC and three thicknesses of HDPE were tested. Each material was tested for parent material strength and seam strength using a 25 mm (1") wide specimen and a grip separation (with and without seam) of 100 mm (4"). A special testing grip was manufactured for the lab tensiometer to fit within the temperature conditioning chamber and to test 25 mm (1") wide specimens.

Three specimens of each material were tested at each of the three temperatures. Parent material specimens were die cut from sheet goods so that the testing was oriented in the cross machine direction (the normal seaming testing direction). Seam specimens were prepared using field wedge welding equipment in 0.5 mm (20 mil) PVC, 0.75 mm (30 mil) PVC, 1.0 mm (40 mil) PVC, 1.0 mm (40 mil) HDPE, 1.5 mm (60 mil) HDPE, and 2.0 mm (80 mil) HDPE. The seam specimens were prepared such that the tensile tests were in the typical cross machine direction. All seam samples for test phases two and three were prepared at the same time with the same lot number of material. Three replicate specimens were tested for each thickness of material.

Specimens were conditioned for a minimum of one hour prior to testing. Each specimen was briefly handled with gloves while being loaded into the testing grips, and the testing chamber was allowed to return to its set temperature before each test. Figure 4 shows the results of the PVC tensile testing while Figure 5 shows the results of the HDPE testing.

The results showed a number of interesting points. First, the linearity of the relationship between temperature and tensile strength appears to be strong. Regardless of the original tensile strength of the material, the variation with temperature appears to be consistent. Tensile strengths were plotted using the units of pressure (MPa) which minimizes variation due to thickness differences between specimens. Using pressure units (MPa) the slopes of the lines remain consistent independent of the material thickness and tensile strength. A "best fit" line was calculated for each set of specimens tested and an average of the slopes of the best fit lines was calculated for each of the test materials. The PVC material had an average slope of -0.21 MPa per degree C, while HDPE showed an average slope of -0.25 MPa per degree C.

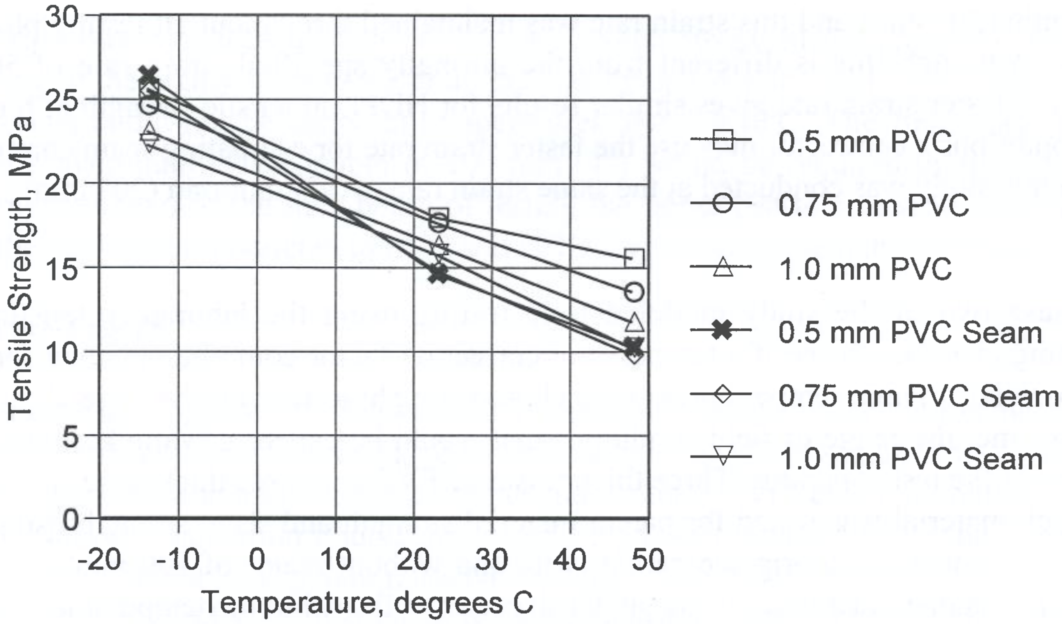

Figure 4. Phase 2 - PVC Tensile Strength at Break vs. Temperature

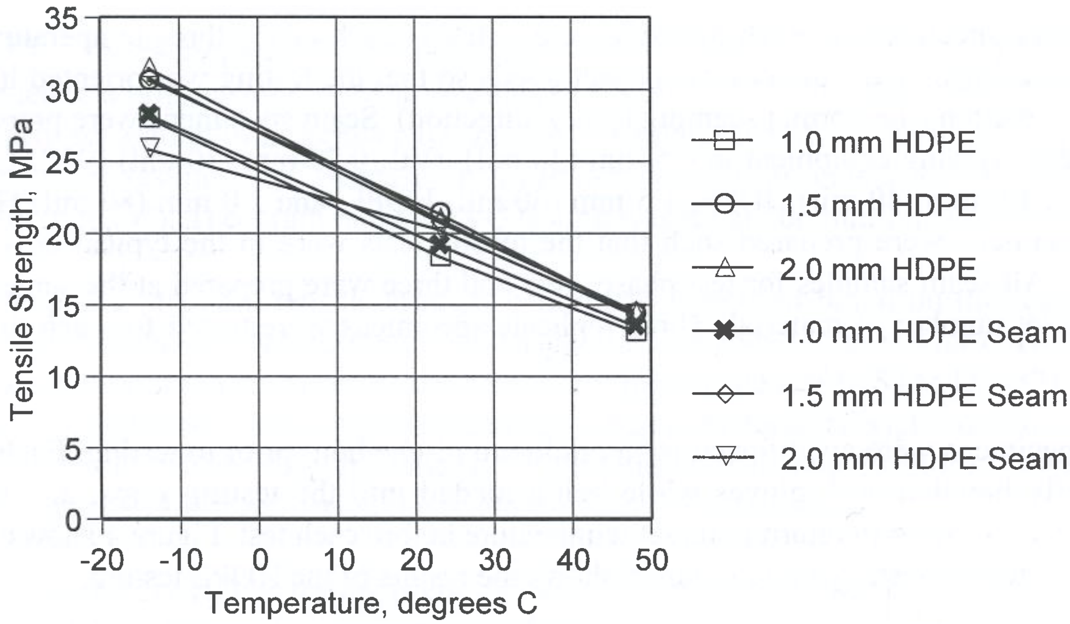

Figure 5. Phase 2 - HDPE Tensile Strength at Break vs. Temperature

Figure 6 shows the relationship between the elongation of the PVC samples and temperature. An average of the slopes of the best fit lines for PVC elongation shows an average slope of 3.3% elongation per degree C. The HDPE elongation data in Figure 7 shows significant departures from consistency and a quantifiable result was not possible. Additional testing would be required to clearly determine the relationship between HDPE elongation at break and temperature.

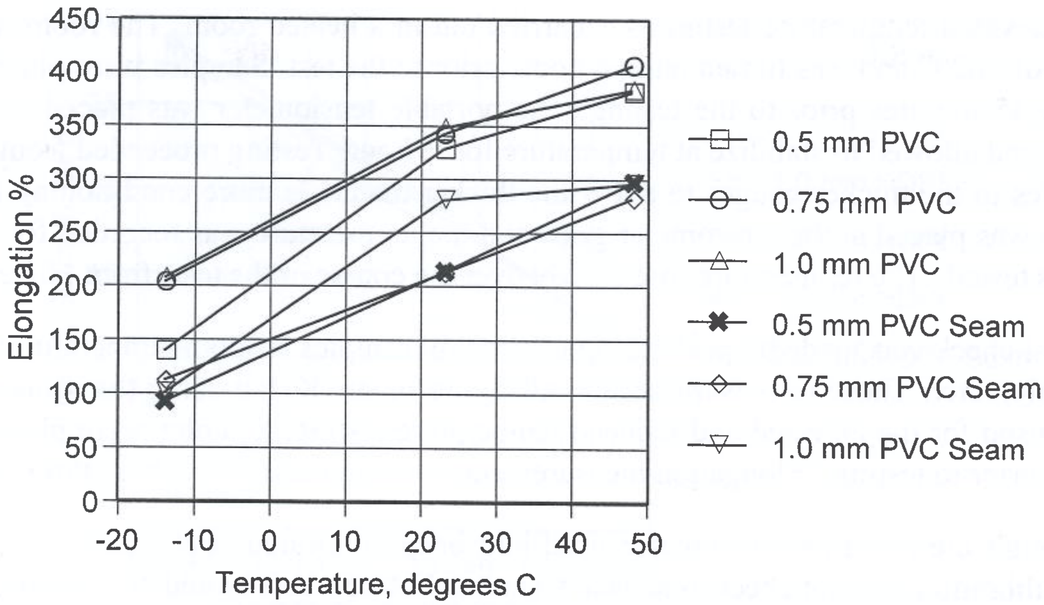

Figure 6. Phase 2 - PVC Elongation at Break vs. Temperature

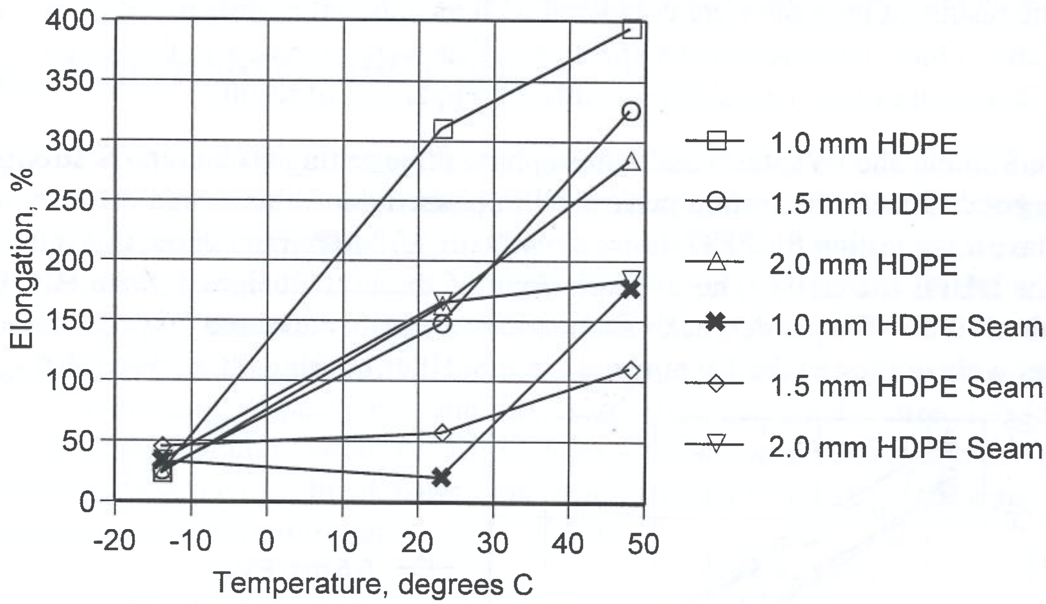

Figure 7. Phase 2 - HDPE Elongation at Break vs. Temperature

PHASE THREE TESTS

The third and final phase of the study attempted to model actual in-field conditions during testing. Using a Columbine "Accura Lite" portable tensiometer samples were tested at elevated and reduced temperatures. For the cold temperature testing a temperature controlled room was used. This room was maintained at a constant temperature of -14°C for 24 hours prior to the commencement of testing. Samples were placed within the chamber 15 hours prior to the test. The portable tensiometer was placed in the room one hour prior to testing to allow it to stabilize at the lower temperature. All samples were tested in the chamber in one session.

The elevated temperature testing was carried out in a heated room. The room had a set temperature of +62°C and was turned on two hours prior to the test. Samples were placed in the heated room 45 minutes prior to the testing. The portable tensiometer was placed within the heated room and allowed to stabilize at temperature for ½ hour. Testing proceeded from the thin gauge samples to the thicker gauges to allow the thicker materials more conditioning time. A thermometer was placed at the tensiometer grips and the temperature was recorded for each set of specimens tested. The temperature rose slowly over the course of the tests from +61 to +66°C.

A final check was made by performing tests on all samples at room temperature with the portable tensiometer. These tests were performed in our plant QC lab using the same portable tensiometer used for the elevated and reduced temperature testing. Samples were placed in the lab 24 hours prior to testing. Elongation measurements were not taken for phase three testing.

Although the portable tensiometer used had been calibrated seven days prior to this testing the calibration was not checked at each test temperature. This would be typical of a field tensiometer where it would be used in a range of temperatures without additional calibration. In this testing the results of the tests were compared with the laboratory tests to see if the test values were consistent. Phase three tests used specimens that were prepared at the same time as the samples tested in phase two. This allowed a direct comparison of results.

Figure 8 shows the PVC test results from phase three testing. The graph is strongly linear and shows a good fit with the testing performed in phase two. The average of the best fit line slopes for phase three testing for PVC shows a result of -0.18 MPa per degree C. Figure 9 shows the results for HDPE materials. The average slope of the best fit lines for the HDPE testing shows a result of -0.22 MPa per degree C. Elongations were not measured for phase three testing. Seam samples were not tested for 1.0 mm and 1.5 mm HDPE during phase three testing.

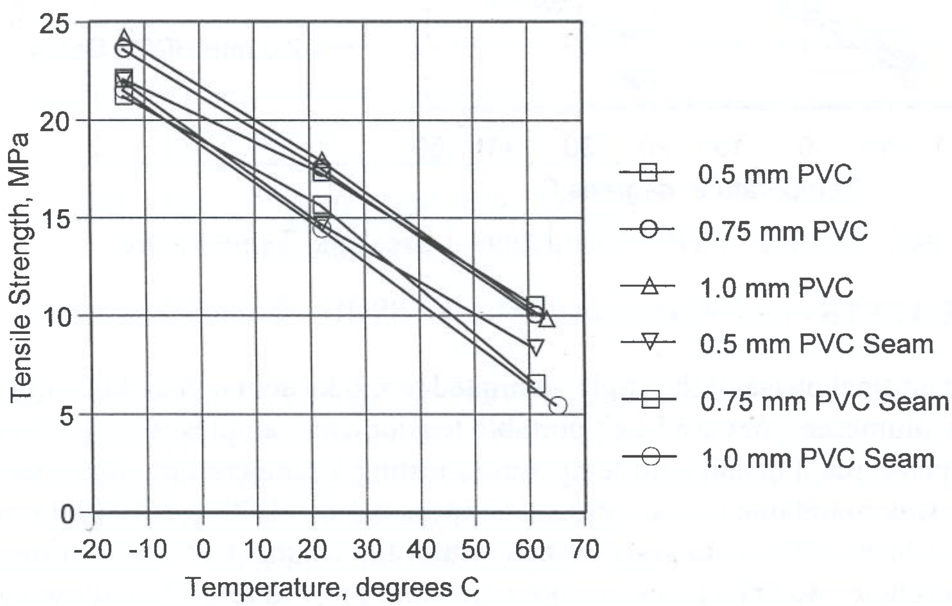

Figure 8. Phase 3 - PVC Tensile Strength at Break vs. Temperature

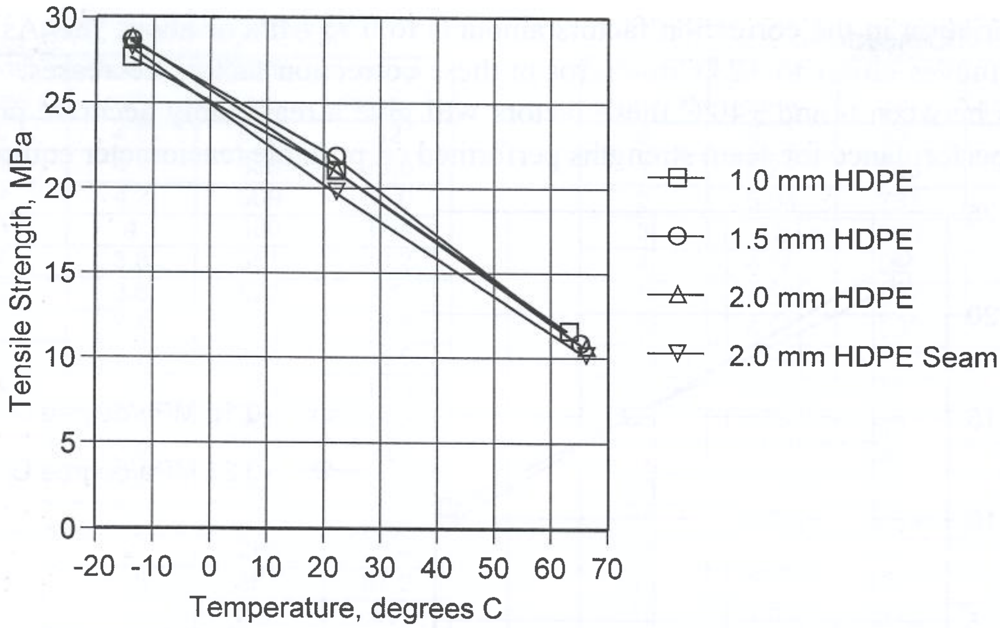

Figure 9. Phase 3 - HDPE Tensile Strength at Break vs. Temperature

TEMPERATURE CORRECTION FACTORS

This study found that a temperature correction factor can be calculated so that samples tested in the field can be adjusted to standard test temperature. This factor was independent of the thickness and initial strength of the materials tested. Although the sample size in this testing program was small, a correction factor was calculated for both PVC and HDPE tensile strength at break and for PVC elongation. The correction factor for PVC was found to be between -0.18 and -0.21 MPa per degree C (phase two and three respectively). The overall average for PVC (average of all slopes from phase two and three testing) was a tensile correction factor of -0.20 MPa per degree C. The elongation correction factor for PVC was 3.3% elongation per degree C. The overall tensile strength at break correction factor for HDPE was -0.24 MPa per degree C (for testing performed at 500 mm/minute).

ACCURACY AND COMPLIANCE PREDICTION

The purpose of the correction factors is to allow an installation contractor to accurately estimate whether compliance testing will be successful when field tests are performed at other than standard temperatures. In order for this estimate to be useful the error in the method needs to be determined. Fortunately, most field seam testing occurs at, or near +23°C. It is only as the testing temperature moves further away from +23°C that the accuracy of these correction factors decrease. Given the example of the two correction factors for PVC of -0.18 and -0.21 MPa per degree C, a line calculated for each slope offers the results as graphed in Figure 10. This graph shows how the accuracy of the correction factor at temperatures near +23°C is a very close approximation, however at the extremes of testing temperature the accuracy diminishes. At

+48°C the variation in the correction factors amounts to 0.75 MPa or about 7%. As the testing temperature moves closer to +23°C the error in these correction factors decreases. For testing temperatures between 0 and +40°C these factors will give a reasonably accurate prediction of compliance performance for seam strengths performed on portable tensiometer equipment.

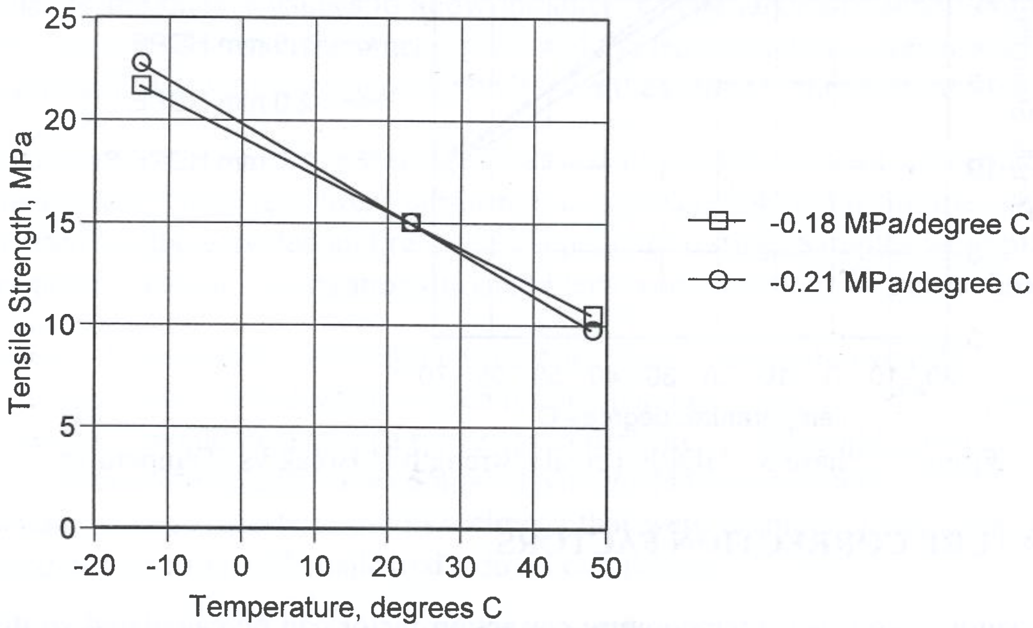

Figure 10. Temperature Correction Factors for PVC Tensile Strength at Break

CONCLUSIONS AND RECOMMENDATIONS

A temperature correction factor was found for each of PVC and HDPE materials that can be used to normalise field seam test results for tensile strength at break to +23°C. These correction factors allow the contractor to predict the specification conformance of seams tested at other than standard test temperature. The correction factors are most accurate at test temperatures close to +23°C and retain reasonable accuracy to the full range of expected testing environments.

For conformance testing, however, our recommendation is that all compliance testing be performed with properly conditioned samples in a temperature controlled laboratory environment. Although this technique of temperature correction will serve the installation contractor well, it will not serve as a replacement for correctly conditioned testing in a laboratory. This testing also shows that the use of portable tensiometers in the field to determine specification compliance by third party QC must consider climate control when performing testing. If temperatures cannot be accurately maintained during conformance testing the validity of the test results cannot be guaranteed.

PVC Correction Chart

Temp degree C	Add to mPa	Add to psi	Temp degree F
0	4.6	667	32
1	4.4	638	33.8
2	4.2	609	35.6
3	4	580	37.4
4	3.8	551	39.2
5	3.6	522	41
6	3.4	493	42.8
7	3.2	464	44.6
8	3	435	46.4
9	2.8	406	48.2
10	2.6	377	50
11	2.4	348	51.8
12	2.2	319	53.6
13	2	290	55.4
14	1.8	261	57.2
15	1.6	232	59
16	1.4	203	60.8
17	1.2	174	62.6
18	1	145	64.4
19	0.8	116	66.2
20	0.6	87	68
21	0.4	58	69.8
22	0.2	29	71.6
23	0	0	73.4
24	-0.2	-29	75.2
25	-0.4	-58	77
26	-0.6	-87	78.8
27	-0.8	-116	80.6
28	-1	-145	82.4
29	-1.2	-174	84.2
30	-1.4	-203	86
31	-1.6	-232	87.8
32	-1.8	-261	89.6
33	-2	-290	91.4
34	-2.2	-319	93.2
35	-2.4	-348	95
36	-2.6	-377	96.8
37	-2.8	-406	98.6
38	-3	-435	100.4
39	-3.2	-464	102.2
40	-3.4	-493	104

HDPE Correction Chart

Temp degree C	Add to mPa	Add to psi	Temp degree F
0	5.52	801	32
1	5.28	766	33.8
2	5.04	731	35.6
3	4.8	696	37.4
4	4.56	661	39.2
5	4.32	627	41
6	4.08	592	42.8
7	3.84	557	44.6
8	3.6	522	46.4
9	3.36	487	48.2
10	3.12	453	50
11	2.88	418	51.8
12	2.64	383	53.6
13	2.4	348	55.4
14	2.16	313	57.2
15	1.92	278	59
16	1.68	244	60.8
17	1.44	209	62.6
18	1.2	174	64.4
19	0.96	139	66.2
20	0.72	104	68
21	0.48	70	69.8
22	0.24	35	71.6
23	0	0	73.4
24	-0.24	-35	75.2
25	-0.48	-70	77
26	-0.72	-104	78.8
27	-0.96	-139	80.6
28	-1.2	-174	82.4
29	-1.44	-209	84.2
30	-1.68	-244	86
31	-1.92	-278	87.8
32	-2.16	-313	89.6
33	-2.4	-348	91.4
34	-2.64	-383	93.2
35	-2.88	-418	95
36	-3.12	-453	96.8
37	-3.36	-487	98.6
38	-3.6	-522	100.4
39	-3.84	-557	102.2
40	-4.08	-592	104

Table 2. Temperature Correction Factors for Tensile Strength at Break.