Long Term Assessment of HDPE Seams Strength

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ABSTRACT: High-density polyethylene (HDPE) geomembrane sheets are assembled through polymer fusion, where a quantity of energy is supplied at the sheets' interface. As long term performance is concerned, one of the observed consequence of time effect is an increased modulus along with a reduced strain value at break. Either a result of time effect or a consequence of welding condition, this strain reduction must be limited in order to avoid local failure, leak development or brittleness. Time effect over secant modulus is discussed and the importance of seaming process is enphasised.

1 INTRODUCTION

High-density polyethylene (HDPE) geomembrane sheets are assembled through polymer fusion, where heat and pressure are combined to ensure polymer homogeneity in the fused area between the seamed membranes. Many types of equipment are now available to construct the seams and they all are well adapted to the known processability of HDPE.

For a seam to be good at the time of installation, it has first to be leak free and then has to show an acceptable stress-strain behavior. Moreover, it must match any ground movements without loosing its original integrity. Therefore deformability govern the long term performance of any HDPE seam because, when used as a permanent hydraulic barrier, geomembranes are required to strain without exhibiting failure even if, as for the design conditions, they are not required to play any structural role (Giroud et al., 1993).

In that respect, it would seem logical to expect that any seam in service must maintain its leak free condition for as long as the geomembrane itself maintains its integrity. The effect of time should not be worse on the seam than it is for the geomembrane itself.

Recognizing the need for information on the long term behavior of HDPE seams, it was decided in 1987 to initiate a special testing program to identify the effect of time on their stress-strain relationship. Results of the program compare the original peel test values to the ones obtained five (5) years later. Results are also compared to previously published data and a general trend is suggested based on the HDPE stress-strain relationship.

2 TESTING PROCEDURE

All the seam samples used to verify the influence of time on the stress-strain relationship of HDPE geomembrane were cut out from a 20,000 square meters final cover installed near Montréal, Québec, Canada, in November 1988.

At that time, some of the samples were immediately tested in laboratory in peel/shear and the others were place in a storage room at ambient conditions. The samples were protected against light exposure and temperature variation during the following five (5) years. In November 1993, they were tested under the same laboratory conditions as per the following standards:

Peel test:	ASTM D4437 (D413, NSF 54 mod.) deformation rate 50mm/min.
Shear test:	ASTM D4437 (D816) deformation rate 50mm/min.

3 RESULTS

From the conformance testing, one would find that the average thickness of the HDPE sheets was 2.04 mm. The density was 0,946 and the carbone black content was 2,25% (ASTM D1603). The mechanical behavior (ASTM D638) of the geomembrane itself is reported as the following:

Table 1 Stress-strain characteristics of the sheet

Tension tests on sheets	Stress (MPa)	Deformation (%)
Yield point	11,83	13,3%
Secant modulus	88,9	(at Yield)
Breaking point	23,99	971%
Secant modulus	2,5	(at Break)

As the main welding method on site, hot air welders were used for the seaming of the geomembrane. Both simple and double seams were obtained from the welding process. The double seams are 60 mm wide with a central channel of 17 mm. The width of the simple seams is 30 mm. The average thickness of the seams is different whether it is measured on a simple or a double seam: the former being 12% thicker. Each tested sample was 25 mm wide and clearly identified. A total of 206 tests were conducted in laboratory to evaluate both peel and shear strength of the seams. The typical values obtained from the peel test results are shown in table 2.

Table 2 Laboratory peel test results

Peel Test (MPa)	Laboratory 1988	Laboratory 1993
Tested samples	124	82
Average Value (at maximum load)	12,07	12,73
Std Deviation (%)	2,87 (23,8%)	2,53 (19,9%)
Minimum value	2,12	2,79
Maximum Value	16,12	16,85

As shown in figure 1, from 1988 to 1993, there is an apparent increase in the strength of the material as measured by the peel test. The average maximum stress value at maximum load was increased in time by 11.4%.

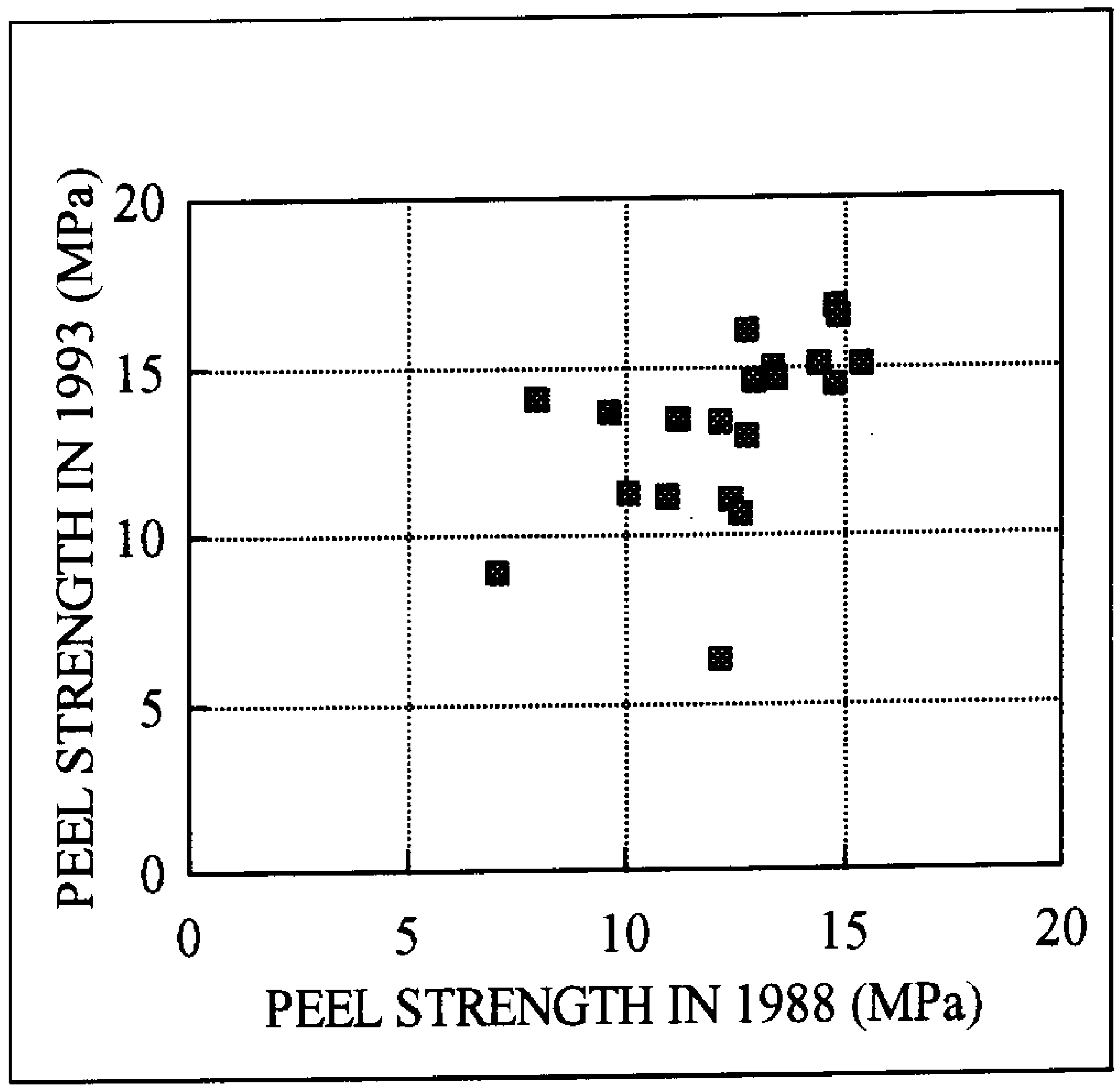

Fig.1 Peel strength comparison from 1988 to 1993

The typical values obtained from the shear test are presented in Table 3.

Table 3 Laboratory shear test results

Shear Test (MPa)	Laboratory 1988	Laboratory 1993
Tested samples	30	57
Average Value (at maximum load)	19,37	18,62
Std Deviation (%)	1,03 (5,3%)	0,81 (4,4%)
Minimum value	17,78	17,18
Maximum Value	21,25	20,96

From 1988 to 1993, the average value of shear stresses at maximum load decreased by 3.9%. The following table summarizes the deformation characteristic of the seamed area.

Table 4 Deformation characteristics of seams

Deformation (%)	Peel tests 1993	Shear tests 1993
Tested samples	82	57
Average Value (at maximum load)	170,4	9,5
Std Deviation (%)	100,4 (58,9%)	1,68 (17,7%)
Minimum value	33,3	7,8
Maximum Value	485,7	12,2

4 DISCUSSION

As the long term role of any FML is to serve as an efficient water barrier, it is more appropriate to express mechanical design criteria for geomembrane in terms of strain than in term of strength. (Giroud et al., 1993). Since strength is always related to strain, then the approach developed in this paper would conciliate stress and strain as part of any secant modulus .

4.1 Welding effect on secant modulus

In that respect, when deformations in shear (table 4) are compared to tension test results (Table 1), one can observe an apparent hardening of the material and calculate a reduction of 28.6% in available strain. The reduction will result in a sharp increase of the secant modulus E_{sec} at yield (maximum load).

$$E_{sec} = \text{Stress at yield/Strain at yield}$$

From a secant modulus of 88,9MPa reported in table 1 for the standard tension test, the new secant modulus after 5 years for the shear test will be 196 MPa. It is an increase of 120%. This result would confirm that seams of olefinic geomembranes have properties differing from the parent material (Kilius, 1993). On the other hand, this hardening process was recognized in the past by Rollin et al (1991). Aside any changes in cristallinity, chain orientation or oxydation resistance, time may be one of the controlling factors.

4.2 Time effect on secant modulus

For the purpose of discussion on time effect, the results of the current testing program are compared to a larger database. Table 5 shows the average values for peel and shear test results of more than 1500 tests on HDPE seam samples (Marcotte and Lombard, 1993).

Table 5 Mechanical characteristic of HDPE seams

Database (MPa)	Peel tests	Shear tests
Tested samples	822	726
Average Value (at maximum load)	13,7	20,3
Std Deviation (%)	1,99 (14,5%)	1,88 (9,3%)
Minimum value	4,6	15,4
Maximum Value	31,8	32,1

In Table 6, the same database gives the results of both shear and peel tests from a deformation point of view.

Table 6 Deformation characteristic of HDPE seams

Database (deformation %)	Peel tests	Shear tests
Tested samples	822	726
Average Value (at maximum load)	67,4	11,2
Std Deviation (%)	43,6 (64,7%)	1,31 (11,7%)
Minimum value	15,8	7,4
Maximum Value	500	17,8

These results apply to standard peel and shear test conducted no more than 48 hours after the seaming process was completed in the field.

The secant modulus at maximum load for the shear test calculated for Table 5 and 6 is 181 MPa. When compared to the sheet's characteristics where the same modulus is around 88.9MPa, an increase of 104% resulting from the seaming process is observed.

Using the secant modulus obtained in paragraph 4.1, it could then be concluded that this change in modulus is rather fast (within 48 hours) and may not be as time dependent as thought before analysis of the five year old samples.

Figure 2 shows the histogram of all secant modulus at maximum load for the shear test results in the database.

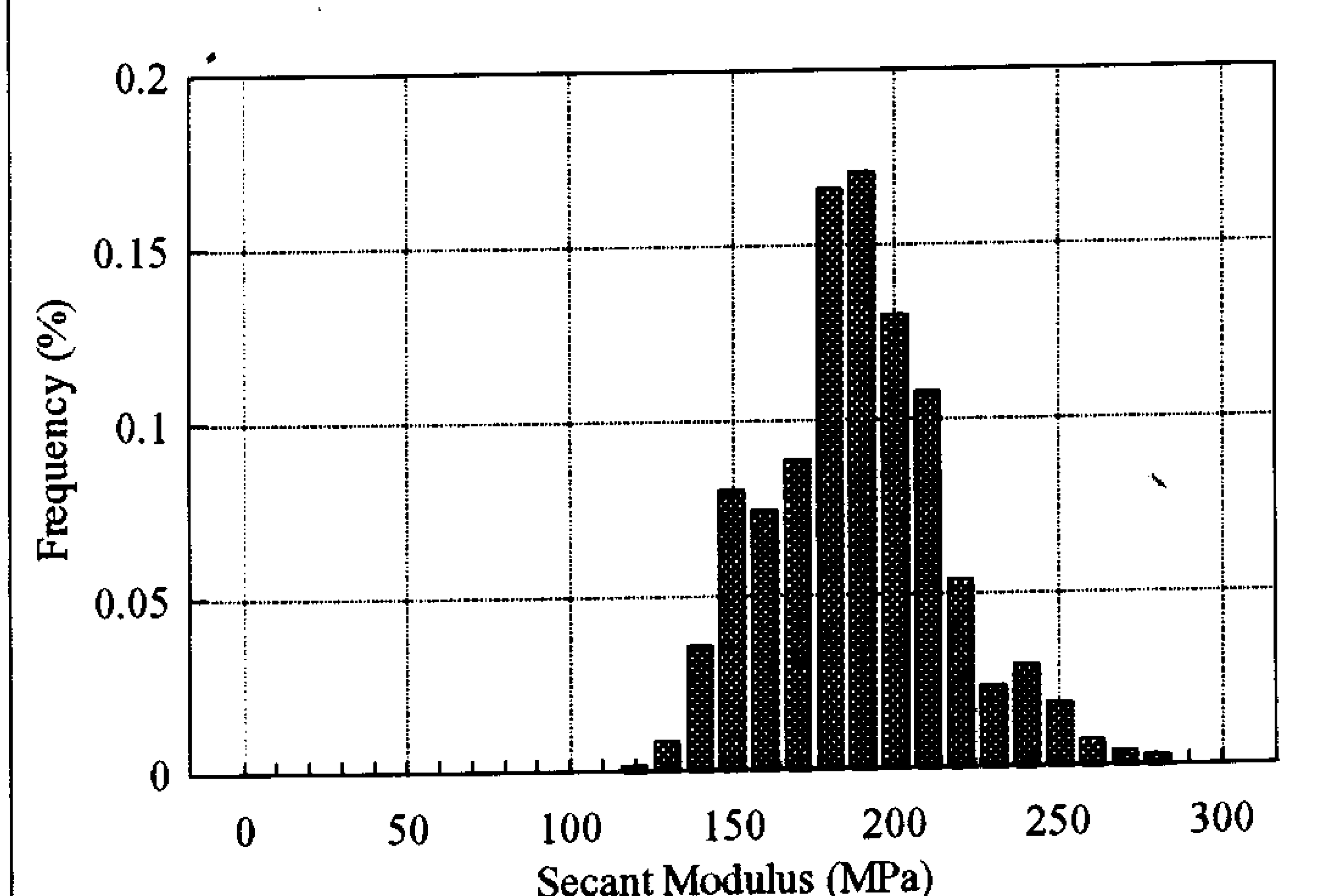

Fig. 2 Secant modulus for shear test results

4.3 Design Consideration

Nowadays, HDPE liners cover the bottom and sides of most newly designed landfills. Some of these facilities are now more than ten years old and the long term behavior of the installed liners is still in the forefront of interest. Seams still are a sensitive element of this interest.

Along with the evolution in time of any polymer or sheet's parameters, strength and deformability are two major variables of the long term behavior of any FML system. Then again, deformability is definitely the controlling factor. On a long term basis, one would prefer a flexible material rather than a rigid one because of the need in available strain.

As current research projects still deal with nip roll pressures, relative widths of seaming machine, energy transfer, crack development and others, it is known that the seaming process may affect the long term behavior of HDPE liner by enhancing an apparent hardening process. The extreme consequence of hardening is then britteness.

Brittle behavior may well then be related to some stress concentration effect (residual stress) created by the seaming process itself. No time period have yet been estimated for the development of brittle behavior.

5 CONCLUSION

In order to evaluate the effect of time on stress-strain behavior of HDPE seam, peel and shear tests were conducted on five year old seams. During the storage period, the seams' samples were not exposed to any chemical or mechanical stresses. From the results obtained, one can draw the following conclusions:

1) The hardening process within the seam is measurable as an increase in secant modulus and a reduction of strain at break
2) The hardening process is rather fast and may not be considered a time dependent process if long term performance is considerered
3) Acceptable strength and strain at break must be specified to fall within a certain range outside of which too strong a seam should be rejected as well as too weak a seam.

Moreover, as long term performance of HDPE liners is concerned, attention must be paid to sustained strain capability rather than to strength because designers should require a geomembrane to follow any ground movement without loss of integrity in time.

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