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A Gas Permeation Test to Assess in situ Quality of stiff Dual Geomembrane Seams

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ABSTRACT: To control in situ stiff geomembrane seams, carried out by means of the thermal hot dual wedge method, a non destructive test is suggested. It consists in pressurizing the gap between both welds by gas injection at a specific pressure and in monitoring the evolution of pressure over time. A permeation parameter can then be estimated under unsteady state conditions. The results show that the non destructive method here presented can reveal poor seams, undetectable by the pressurized dual seam method currently used in situ to assess the continuity of the seams. A new test can thus be included in the Construction Quality Control/Construction Quality Assurance activities to control seams quality, in pond applications where stiff geomembranes are placed.

1 INTRODUCTION

Assessing seam quality of geomembranes is very important: 65% of leaks through uncovered geomembranes (Rollin et al., 2002) and 6% of leaks through covered geomembranes (Nosko & Touze-Foltz, 2000 and Colucci & Lavagnolo, 1995) are due to seam defects. Typically, it is accomplished by destructive (shear and peel tests) and non destructive test methods (for instance: the pressurized dual seam method for double welded seams).

Shear and peel tests provide information only about the limited portion of the seam corresponding to the specimen tested. Furthermore, they require repairs and are time consuming; their frequency must be then optimized. Also, the results of such tests have never been correlated to permeation characteristics.

As for the pressurized dual seam method, it provides information about the seam continuity. This method detects only severe defects and does not give any quantified information about the real performance of the seam. Additionally, the pressurized dual seam method cannot be generally considered as a substitute for mechanical tests, except for thermally bonded PVC geomembranes seams with air channel as shown by Thomas et al. (2003) and by Stark et al. (2004). These authors showed there is a relationship between the welded seam burst strength and the seam peel strength, validated for PVC geomembranes and for a given sheet temperature. This method is interesting since it is not destructive and it tests the whole seam, but it cannot be applied to stiff geomembranes and it concerns only mechanical properties.

A non destructive test to evaluate the permeation performance of a double welded seam on site by a quantitative measurement would be very important for the Construction Quality Control/Construction Quality Assurance of geomembranes. The goal of the present paper is to present such test: the gas permeation pouch test.

2 PRESENTATION OF THE PERMEATION POUCH TEST

The gas permeation pouch test method was designed by Pierson & Barroso (2002). It is actually quite similar to the pressurized dual seam method, consisting of pressurizing the gap between both welds (pouch) by gas injection at a specific pressure $p(0)$ and in measuring its decrease over time $p(t)$. If this pressure decrease is not too fast and if the atmospheric pressure and ambient temperature are constant (corresponding to a specific "pseudo steady state"), a gas permeance P_G (mol s^{-1} Pa^{-1}) can be determined from Eq. 1:

$$P_G = \frac{GTR}{\Delta p_G} \qquad (1)$$

where GTR (mol s^{-1}) is the gas flow through the specimen, obtained from the ideal gas law (if the pouch volume and the ambient temperature are known) and from the variation of pressure over time, and Δp_G (Pa) is the mean partial pressure difference of penetrant molecule G in adjacent gases on both sides of the geomembrane.

The determination of P_G from Eq. 1 requires a constant volume of the pouch. For stiff geomembranes (e.g. HDPE geomembranes), the volume variations observed in laboratory are negligible as reported by Pierson & Barroso (2002). In this case, P_G can be obtained from Eq. 1.

If a gas permeation pouch test is carried out in situ, the variations $p(t)$ will not only be due to the gas diffusion from inside to outside the pouch, but also to the variations in the atmospheric pressure and ambient temperature. Additionally, in the case of poor seams, the pressure decrease is faster and the "pseudo steady state" cannot be defined.

Therefore, it is impossible to determine the gas permeance, P_G, of a double hot wedge seam on site and an "unsteady state parameter" must be then defined.

From the observation of the variations of the absolute pressure inside the specimen $p(t)$ (see Fig. 2), it is possible to show that, after a delay time, t_0, Eq. 2 may approach with reasonable accuracy the experimental data $p(t)$.

$$p(t) = p_{atm} + \left[p(0) - p_{atm}\right] e^{\frac{-t}{\tau}} \qquad (2)$$

where p_{atm} is the atmospheric pressure (Pa), $p(0)$ is the absolute initial pressure of the gas inside the specimen (Pa), t is the time (hours), and τ is a constant, herein termed as time constant (hours), which may be considered a real permeation parameter: in the case of a good seam, a long time is necessary to achieve the final steady state (corresponding to atmospheric pressure inside the pouch), leading to a high time constant value. On the other hand, this final steady state would rapidly be achieved in the case of a poor seam, corresponding to a small time constant value.

Quantity τ can be easily determined: it is the inverse of the slope of the linear function ln $Z(t)$ defined in Eq. 3 and derived from Eq. 2 for $t \geq t_0$:

$$\ln Z(t) = \frac{-t}{\tau} \quad \text{where: } Z(t) = \left[\frac{p(t) - p(\infty)}{p(0) - p(\infty)}\right] \qquad (3)$$

Time t_0 is a delay time corresponding to the beginning of the test, during which Eq. 2 is not valid. It is determined by optimizing the coefficient of linear correlation, r^2, of the function ln $Z(t)$.

With respect to the determination of P_G, this method cannot be applied if the pouch volume is not constant, which means again that it only concerns stiff geomembranes.

3 EXPERIMENTAL RESULTS

Gas permeation pouch tests were carried out using HDPE smooth geomembrane, 2.0 mm thick. Two different tests were carried out. One test, using a 10 meter long specimen, was tested in an air conditioned laboratory (air temperature: 20 ± 2°C; relative humidity: 65 ± 5%) and it is herein termed as lab-specimen. The other one, a 5 meter long specimen, was tested outdoors to simulate field conditions. This specimen is herein termed as outdoors-specimen (Fig. 1). The tests were carried out using nitrogen gas.

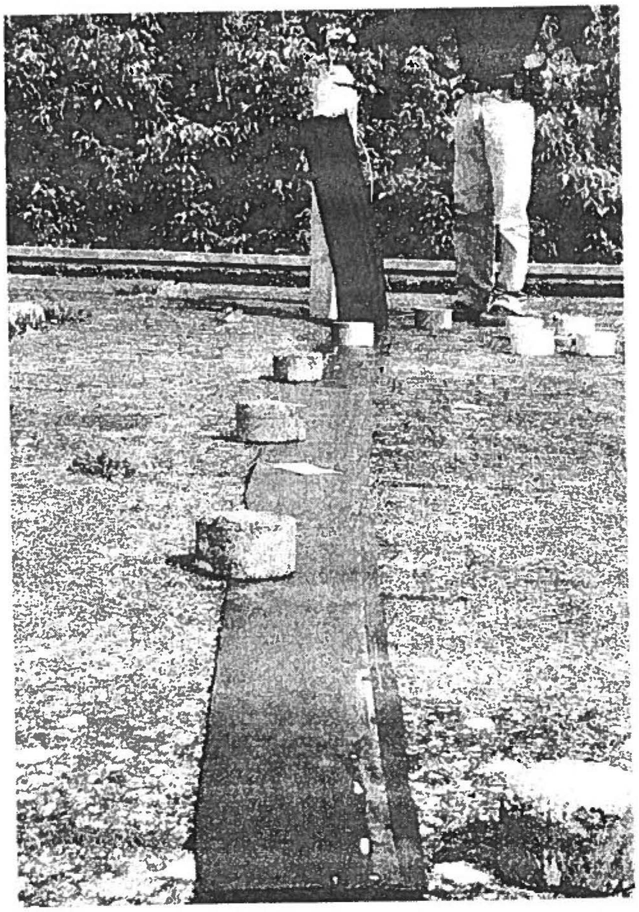

Figure 1. Large-scale test carried out outdoors

Figures 2 and 3 show the variations *p(t)*, respectively, in the air-conditioned laboratory and outdoors.

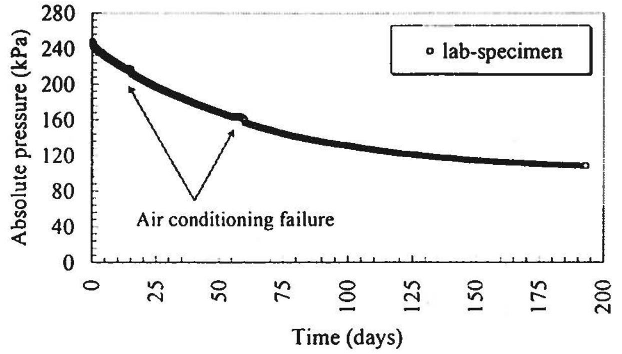

Figure 2. Variation over time of the pressure inside the large-scale specimen tested in laboratory

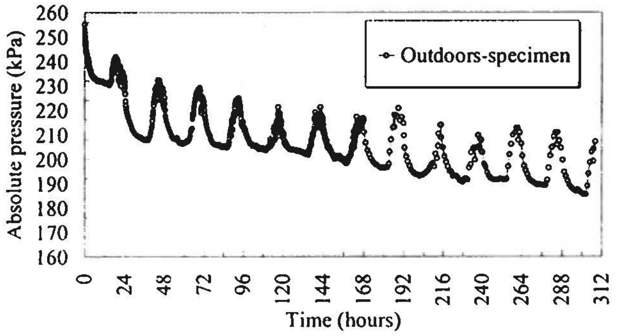

Figure 3. Variation over time of the pressure inside the large-scale specimen tested outdoors

The "wave behaviour" presented by the outdoors-specimen is due to the variations of the geomembrane temperature as a result of the important absorption of solar radiations during the day (black product). It was then necessary to calculate each day the quantity *Z(t)* for the same geomembrane temperature. During the test, it was observed that the influence of the atmospheric pressure variations was negligible, compared to the influence of the sheet temperature.

Fig. 4 shows the variations ln *Z(t)*, two days after the beginning of the test (corresponding to the delay time t_0), for the tests carried out with both specimens tested. The corresponding time constants are compatible: τ = 2000 ± 400 hours for the lab specimen and τ = 1700 ± 400 hours for the outdoors-specimen.

The gas permeance was also calculated for the lab-specimen, even if the variation *p(t)* did not allow a definition of a "pseudo steady state" (no gas permeance was determined for the outdoors-specimen because, in addition to the variations *p(t)*, the ambient temperature is too variable). The following value was obtained (per unit of length):

$$P_{N2L} = 1.2 \times 10^{-15} \pm 0.2 \times 10^{-15} \text{ mol m}^{-1} \text{ s}^{-1} \text{ Pa}^{-1}.$$

This value is quite in agreement with the mean gas permeance obtained by Barroso et al. (2006) for small-scale specimens $P_{N2L} = 10^{-15} \pm 0.2\times10^{-15}$ mol m^{-1} s^{-1} Pa^{-1} (value obtained under "pseudo steady state" conditions).

Such results show that it is possible to compare the results obtained on site from the gas permeation pouch test with the results obtained in the laboratory, on a reference specimen, from the same test conducted under the same conditions. Different time constants were calculated for the outdoors-specimen and for different time intervals after the two day delay time, showing that a minimum time of 6 days is necessary to obtain a time constant compatible with the one calculated at the end of the test.

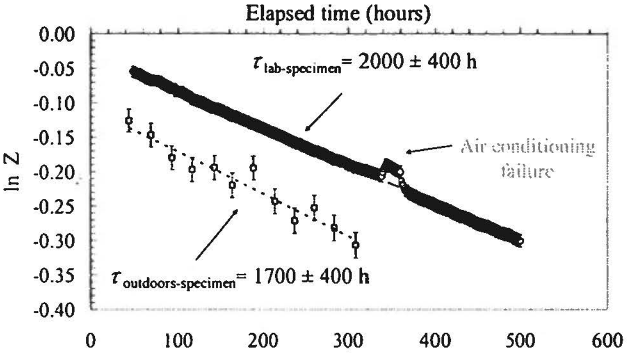

Figure 4. Variation over time of quantity ln *Z* for specimen tested in laboratory (lab-specimen) and outdoors (outdoors-specimen)

To study if there is a correlation between the permeation characteristics and the mechanical strength of the seams, peel tests were also carried out, both with the lab-specimen and the outdoors specimen. These tests were conducted according to the ASTM D 6392 and on both welds of each seam (inner and outer welds).

The results of peel tests are given in Table 1 and compared to seams acceptance criteria proposed by the GRI (2003). Such results, complemented by tests conducted by Barroso et al. (2006) on different small scale specimens, showed that a seam validated by a peel test is also a good seam from a permeation point of view, with a proved safety margin. Results also showed that peel tests are better adapted for the calibration of seam parameters than the gas permeation pouch test.

Table 1. Results of the peel tests

Mean peel strength (kNm^{-1})	inner weld	27.3
	outer weld	22.9
Mean shear strength (kNm^{-1})		39.5
Acceptance criteria from GRI (2003)		Pass

4 CONCLUSION

This paper presents on a non destructive test, the gas permeation pouch test, to control the quality of the seams in situ.

Large-scale gas permeation pouch tests were performed both in laboratory and in field conditions (outdoors) using HDPE dual seamed geomembranes and nitrogen gas. The results obtained were interpreted in terms of time constant (τ), a parameter evaluated in unsteady state conditions. The idea behind this calculation is that, regardless of the length of the seam, a specific material tested with a specific gas is characterized by a specific τ, which may be measured in the laboratory for a reference seam. The values of τ measured in situ over a week (in case of poor seams, this time period is shorter) can be compared with the one of the reference seam tested in laboratory.

The most significant findings to be drawn from the results obtained are as follows: (i) the gas permeation pouch test was able to identify poor seams which would have been accepted in the field after a control based only on the pressurised dual seam method, suggesting that the tools presently used on site need to be improved; (ii) the comparison between the results of gas permeation pouch tests and peel tests showed seam validated by a peel test is also a good seam from a permeation point of view and that mechanical tests are better adapted than gas permeation pouch test to optimize seam parameters and to compare aged specimens in landfills to new specimens; and (iii) it appears that it is possible to assess the quality of double thermal-hot dual wedge seams, from a non-destructive test conducted on site, by determining the time constant.

These results suggest that the gas permeation pouch test can be included in the Construction Quality Control/Construction Quality Assurance for stiff geomembranes, with the clear advantage of it being a non destructive test method.

As for the limitations, this test concerns only stiff geomembranes. Also, the minimum test duration is about six days, which is a long time, unavoidable for a permeation test, but generally unacceptable when the geomembrane must be quickly covered in landfill applications, for example. Therefore, the application field of the gas permeation pouch test will preferably be pond applications, such as leachate ponds, where no seam defect can be acceptable.

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