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Relationship between temperature and peel strength of double hot wedge HDPE geomembranes seams

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ABSTRACT: In landfills, the decision of conformity/non-conformity of HDPE geomembranes double hot wedge seams is usually evaluated by destructive tests: peel and shear tests. Laboratory tests were conducted to study the influence of the temperature on peel strength of the seams. Eleven temperatures, ranging from 4 to 36 °C, were considered. Two samples of HDPE geomembrane seams were used. For each temperature, both peel strength value and mode of rupture were recorded. Based on the results obtained, some correlations between peel strength and temperature values are proposed. As in the field it is not always easy to guarantee the accomplishment of the tests at the standardised temperature these correlations are very important to support the right decision of acceptance or rejection of the field seams.

1 INTRODUCTION

In landfills, high density polyethylene (HDPE) geomembranes are typically used. This type of geomembranes is generally seamed by thermal fusion methods, namely by the dual hot wedge method. The mechanical strength of these seams is usually assessed through shear and peel tests, performed in the field and in the laboratory. The shear test simulates the stress induced by the mechanical and thermal contraction on a seam in service conditions and the results are used to assess whether the seams fail before the geomembrane itself. The peel test is used to evaluate the adhesion strength between two geomembrane panels (Rollin et al. 1994).

Several seam acceptance criteria have been proposed (e.g., NSF 54 1993, Haxo & Kamp 1990; Daniel & Koerner 1993; Peggs 1994; Benneton & Gerard 2002; GRI-GM19 2002), based on the results of the peel and shear tests. The results of these tests are highly dependent on the temperature. Tests are currently carried out according to ASTM D 6392, which specifies a testing temperature equal to 23 °C (±2 °C). However, in field, it is not always possible to perform the tests with the standardised temperature. It follows, that seams can be wrongly rejected or accepted.

The main objective of this paper is to show the influence of the temperature on the results of field peel tests and the consequences that it can have in the decision of acceptance or not acceptance of the seams, as, in field, it is not always easy to guarantee the accomplishment of the tests at standardised temperature.

2 EXPERIMENTAL WORK

2.1 *Materials*

Two different HDPE geomembranes were used. These are described in Table 1 and are referred to A and B.

Table 1. Characteristics of the geomembranes used according to the manufactures.

Properties	Geomembrane A	Geomembrane B
Thickness (mm)	2.00 (ASTM D 751)	2.00 (EN ISO 2286-3)
Specific mass (g/cm^3)	0.94 (ASTM D 792)	0.94 (DIN 53479-A)
Tensile stress at yield (kN/m)	36 (ASTM D 638)	34 (EN ISO 527-3)
Strain at yield (%)	13 (ASTM D 638)	11 (EN ISO 527-3)
Tensile stress at break (kN/m)	66 (ASTM D 638)	66 (EN ISO 527-3)
Strain at break (%)	> 800 (ASTM D 638)	> 700 (EN ISO 527-3)

Samples consisted of double hot wedge seams. They were prepared by two different manufacturers, using their own equipment. Peel tests were conducted at eleven different temperatures to evaluate the mechanical strength of the seams.

2.2 *Test method*

Tests were conducted based on the ASTM D 6392, but at different temperatures besides the one indicated in this standard (23 °C). Temperatures used were as follows: 4, 7, 10, 13, 17, 20, 23, 27, 30, 33 and 36 °C. For each temperature, five strip specimens (25 mm wide and 150 mm long) were taken across the seam and the unseamed ends were placed in the grips of a tensile machine. The initial grip separation was 25 mm and the rate of grip separation was 50 mm/minute. Peel tests were performed for external track of the seam. Both peel strength and rupture mode were recorded.

Shear tests were not performed in this study because in these tests failure typically occurs in the sheet adjacent to the weld and thus strength values correspond mostly to unseamed geomembrane sheets (Barroso 2005). This approach is in agreement with the recommendations repeatedly made by (e.g., Peggs 1994, 1996). According to this author, shear strength does not seem to provide useful information about seam bond.

2.3 *Assessement of seam tests results*

Test results were evaluated based on the GRI-GM19 (2002). For 2 mm thick HDPE geomembrane seams, it specifies that the peel strength of four out of five specimens tested should meet or exceed 21.2 kN/m (for a temperature of 23 °C); the fifth must meet or exceed 80% of the given value.

Concerning the rupture mode, GRI-GM19 (2002) specifies that codes AD and AD-BRK > 25% (Figure 1) are considered unacceptable.

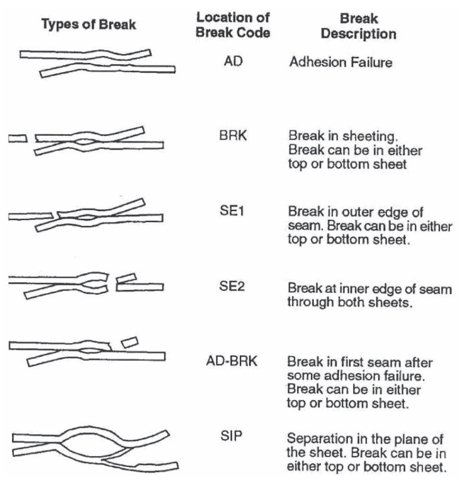

Figure 1. Rupture codes (from ASTM D 6392).

3 RESULTS AND DISCUSSION

For each temperature, results obtained in terms of peel strength and rupture mode are summarised in Tables 2 to 5, for both geomembrane samples (A and B).

From a peel strength point of view, it can be observed that all values are higher than the minimum value suggested by GRI-GM19 (2002).

Table 2. Geomembrane A: peel strength values at different temperatures.

Temperature (°C)	**Peel strength** (kN/m)				
4.2	30.8	30.8	31.0	29.1	31.9
6.8	30.4	30.4	30.4	30.4	30.4
9.7	29.8	29.8	29.8	29.8	29.8
12.6	27.4	27.4	27.4	27.4	27.4
16.5	27.8	27.8	27.8	27.8	27.8
19.7	27.4	27.4	27.4	27.4	27.4
23.6	26.1	26.1	26.1	26.1	26.1
27.4	24.6	24.6	24.6	24.6	24.6
30.0	24.8	24.8	24.8	24.8	24.8
32.8	24.3	24.3	24.3	24.3	24.3
35.9	24.2	24.2	24.2	24.2	24.2
Specimens	P1	P2	P3	P4	P5

Table 3. Geomembrane A: mode of rupture.

Temperature (°C)	**Rupture code** (*)				
4.2	SE1	SE1	SE1	SE1	SE1
6.8	SE1	SE1	SE1	SE1	SE1
9.7	SE1	SE1	SE1	SE1	SE1
12.6	SE1	SE1	SE1	SE1	SE1
16.5	SE1	SE1	SE1	SE1	SE1
19.7	SE1	AD-BRK>25%	SE1	SE1	SE1
23.6	SE1	SE1	SE1	SE1	SE1
27.4	SE1	AD-BRK>25%	SE1	SE1	SE1
30.0	SE1	SE1	SE1	SE1	SE1
32.8	SE1	SE1	SE1	SE1	SE1
35.9	SE1	SE1	SE1	SE1	SE1
Specimens	P1	P2	P3	P4	P5

(*) according to Figure 1

Table 4. Geomembrane B: peel strength values at different temperatures.

Temperature (°C)	**Peel strength** (kN/m)				
4.2	36.4	36.4	36.4	36.4	36.4
6.8	35.6	35.6	35.6	35.6	35.6
9.7	35.6	35.6	35.6	35.6	35.6
12.6	34.3	34.3	34.3	34.3	34.3
16.5	33.2	33.2	33.2	33.2	33.2
19.7	32.4	32.4	32.4	32.4	32.4
22.8	32.2	32.2	32.2	32.2	32.2
27.5	30.7	30.7	30.7	30.7	30.7
30.0	30.0	30.0	30.0	30.0	30.0
32.8	29.4	29.4	29.4	29.4	29.4
35.9	28.5	28.5	28.5	28.5	28.5
Specimens	P1	P2	P3	P4	P5

Table 5. Geomembrane B: mode of rupture.

Temperature (°C)	Rupture code (*)				
4.2	SE1	SE1	SE1	AD	SE1
6.8	SE1	SE1	SE1	SE1	SE1
9.7	SE1	SE1	SE1	SE1	SE1
12.6	SE1	SE1	SE1	SE1	SE1
16.5	SE1	SE1	SE1	SE1	SE1
19.7	SE1	SE1	SE1	SE1	SE1
22.8	SE1	SE1	SE1	AD-BRK>25%	SE1
27.5	SE1	SE1	SE1	SE1	SE1
30.0	SE1	SE1	SE1	SE1	SE1
32.8	SE1	SE1	SE1	SE1	SE1
35.9	SE1	SE1	SE1	SE1	SE1
Specimens	P1	P2	P3	P4	P5

(*) according to Figure 1

As for the rupture mode, four specimens did not meet the acceptance criteria. These specimens were as follows: P2 tested at 19.7 and 27.4 °C, for geomembrane A; and P4 tested at 4.2 and 22.8 °C, for geomembrane B. Results obtained for these specimens were disregarded in the study of the influence of the temperature on the peel strength (next section).

3.1 *The influence of the temperature on the peel strength*

The peel strength values at different temperatures are presented in Figure 2, for geomembranes A and B. It can be observed that peel strength trend to decreases when temperature increases.

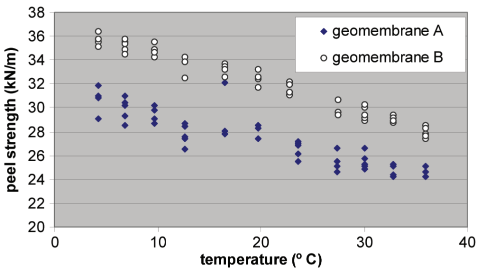

Figure 2. Variation of the peel strength values with the temperature.

3.2 *Interpretation of the results based on geomembrane microstructure*

HPDE is mainly formed by linear polymeric chains with few branches which tend to be closely packed together and in parallel to each other, leading to a compact system (thus with high density) and regions with regular structure said to be crystalline.

The crystallinity degree influences the mechanical resistance of the end product. For identical polymerization degree, higher crystallinity degree, which is due to the polymeric chains being more closely packed together and therefore stronger intermolecular forces between the chains, leads to higher mechanical material resistance.

The molecular mechanisms behind geomembranes seamed by thermal fusion methods are related to heating supplies which lead to internal polymeric motions (vibration, stretching, rotation, and translation) aiming to absorb the energy to which they are exposed to. These internal motions allow the intermolecular forces between the chains of seamed geomembranes to weaken and the chains to slide over one another. The decrease of temperature that follows leads to re-solidification and development of new intermolecular forces without significative differences in the molecular structure and polymeric properties.

When peel tests are performed at higher temperatures, the polymeric structures are less crystalline and the intermolecular forces between the chains are weaker, thus the relative movements between chains are easier and therefore the material strength values are lower (Figure 2).

3.3 *Correlation between the peel strength and the temperature*

In field it is not always easy to guarantee the accomplishment of the peel tests at the standardized temperature (23 °C). A proper correction of the effect of the temperature on field peel test results is thus needed to support the right decision of conformity/non-conformity of the seams, otherwise seams can be wrongly rejected or accepted. Therefore, the establishment of correlations between the peel strength and the temperature can be very useful. Several relationships were obtained, and the results are presented in Table 6.

Table 6. Peel strength and temperature correlations.

Correlations type	Geomembrane A	Geomembrane B
linear	$\boldsymbol{P} = -0.19\,\boldsymbol{T} + 31.25$ $\boldsymbol{R^2} = 0.82$	$\boldsymbol{P} = -0.25\,\boldsymbol{T} + 37.03$ $\boldsymbol{R^2} = 0.96$
logarithmic	$\boldsymbol{P} = -2.91\ln(\boldsymbol{T}) + 35.59$ $\boldsymbol{R^2} = 0.77$	$\boldsymbol{P} = -3.71\ln(\boldsymbol{T}) + 42.57$ $\boldsymbol{R^2} = 0.86$
exponential	$\boldsymbol{P} = 31.43\,e^{-0.007\,\mathrm{T}}$ $\boldsymbol{R^2} = 0.83$	$\boldsymbol{P} = 37.35e^{-0.007\,\mathrm{T}}$ $\boldsymbol{R^2} = 0.96$
polynomial	$\boldsymbol{P} = 0.01x^2 - 0.21\boldsymbol{T} + 31.40$ $\boldsymbol{R^2} = 0.82$	$\boldsymbol{P} = -0.02x^2 - 0.18\boldsymbol{T} + 36.53$ $\boldsymbol{R^2} = 0.96$

P: peel strength (kN/m)
T: temperature (°C)

For geomembrane B, linear, exponential and polynomial correlations appear to be very good, in terms of correlation coefficient, $R^2 = 0.96$. Logarithmic correlation is qualitatively inferior ($R^2 = 0.86$). For geomembrane A, the correlations obtained are inferior to those obtained for geomembrane B, due to the largest deviation of peel strength results, but similar conclusions can be taken. As the differences between linear, exponential and polynomial correlations are not significant, the linear correlation was chosen, for simplicity (see Figure 3).

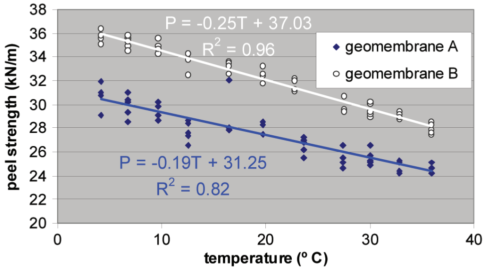

Figure 3. Peel strength and temperature linear correlation.

4 CONCLUSIONS

Based on the results obtained and the observations reported herein, we found that the relationship type between temperature and peel strength of double hot wedge HDPE geomembrane seams is linear. This knowledge will easily allow estimating the peel strength value at standardized temperature, starting from other values of field peel strength at different temperatures, which is needed to support the decision of conformity/non-conformity of the seams according with most seams acceptance criteria.

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REFERENCES

ASTM D 6392 (1999). "Standard Test Method for Determining the Integrity of Nonreinforced Geomembrane Seams produced Using Thermo-Fusion Methods", *American Society for Testing and Materials*, West Conshohocken, Pennsylvania, USA.

Barroso, M.C.P. (2005). "Fluid Migration through Geomembrane Seams and through the Interface between Geomembrane and Geosynthetic Clay Liner", *Ph.D. thesis*, Universities of Grenoble and Coimbra, France and Portugal, 215.

Benneton, J.P. and Gerard, Y. (2002). "Mechanical Strength Evaluation of Geomembrane Welds-Welding Factors", *Proceedings of Seventh International Conference on Geosynthetics, Vol. 4*, Nice, France, pp 1411-1414.

Daniel, D.E. and Koerner, R.M. (1993). "Quality Assurance and Quality Control for Waste Containment Facilities", *United States Environmental Protection Agency Report EPA/600/R-93/182*. Cincinnati, OH, USA, pp 305.

GRI-GM19 (2002). Standard Specification for Seam Strength and Related Properties of Thermally Bonded Polyolefin Geomembranes, (up dated in 2003).

Haxo, H.E., Jr and Kamp, C.L. (1990). "Destructive Testing of Geomembranes Seams: Shear and Peel Testing of Seam Strength", *Geotextile and Geomembranes, No. 9*, pp 69-404.

NSF 54 (1993). "Flexible Membrane Liners", *National Sanitation Foundation*, Ann Arbor, Michigan, USA, pp 30.

Peggs, I.D. (1994). "Testing Program to Assure the Durability of Geomembranes, Landfilling of Waste: Barriers", Edited by T.H. Christensen; R. Cossu and R. Stegmann, Published by E & FN Spon, pp 413-429.

Peggs, I.D. (1996). "A Reassessment of HDPE Geomembrane Specifications", *Proceedings of Geosynthetics: Applications, Design and Construction*, Balkema, Rotterdam, Nederland, pp 693-695.

Rollin, A.L., Vidovic, A. and Ciubotariu, V. (1994). "Assessment of HDPE Geomembrane Seams, Landfilling of Waste: Barriers", Edited by T.H. Christensen; R. Cossu and R. Stegmann, Published by E & FN Spon, pp 377-391.