TECHNICAL SESSIONS

PVC geomembranes in dams: influence of test temperature on seams peel and shear strength

M. G. Lopes
Instituto Superior de Engenharia de Lisboa, Portugal (glopes@dec.isel.ipl.pt)

M. Barroso
Laboratório Nacional de Engenharia Civil, Portugal (mbarroso@lnec.pt)

ABSTRACT: The PVC geomembranes are the most commonly used for dams. The success of this waterproofing system depends on the quality of which the geomembranes seams are made. The seams must be evaluated in terms of continuity/watertightness and mechanical strength, the latter being assessed by peel and shear tests. In this work, the influence of test temperature on the peel and shear strength of PVC geomembrane seams is studied. This issue is important because, sometimes in the field, it is not possible to carry out these tests at the standard temperature of 23ºC (± 2ºC), raising questions on their acceptance/rejection. Three geomembranes (1.5 mm, 2.0 mm and 3.0 mm thickness), with dual track thermo-fusion seams, were evaluated by peel tests according to ASTM D 6392 standard, at temperatures ranging from 5ºC to 41 ºC. One of the geomembranes (3.0 mm thickness) was also tested by shear tests, according to the same standard. Results showed that test temperature has a small influence on the peel strength values of the PVC geomembrane seams, contrary to what happens with HDPE geomembranes. Results also showed a significant decrease in shear strength with increasing test temperature, as was also verified with HDPE geomembranes.

Keywords: dams, PVC geomembranes, seams, peel strength, shear strength

1 INTRODUCTION

The PVC (polyvinyl chloride) geomembranes are the most commonly used for dams (ICOLD, 2010). The success of these waterproofing systems depends on the quality with which the geomembranes seams are made. The thermally bonded method is normally suited for PVC geomembranes thicker than 1.5 mm, and the quality of the seams must be assessed in terms, either of watertightness, through non-destructive tests, or mechanical resistance, through destructive tests. Destructive tests are generally carried out according to the ASTM D 6392 (2018) standard, at a temperature of 23ºC (± 2ºC). However, *in situ*, sometimes it is not possible to attain this temperature, raising questions about the acceptance / rejection of seams.

Field tests carried out by Lopes & Lopes (2001) and Lopes *et al.* (2006) in HPDE geomembrane seams at low temperatures (< 18ºC) presented inaccurate results, once they may show that seams strength is satisfactory when in fact it is not. As similar studies carried out in PVC geomembranes seams are unknown, this study focuses on this problem. To achieve this objective three PVC geomembranes with different thicknesses (1.5 mm, 2.0 mm and 3.0 mm) with dual track thermo-fusion seams were used.

The tests were carried out according to the ASTM D 6392 standard, at 12 different temperatures ranging from 5ºC to 41 ºC and the results are reported both in terms of quantitative strength and the locus-of-break code, in the line the most engineering specifications. This study is an extension of the work carried out by Sanfona (2018).

2 EXPERIMENTAL WORK

2.1 *Materials*

The main properties of the three geomembranes (A, B, C) used in the experimental work are summarized in Table 1, based on their Technical Data Sheets, given by the suppliers.

Table 1. Geomembranes properties based on the Technical Data Sheets (adapted from Sanfona, 2018)

Properties	Geomembrane A	Geomembrane B	Geomembrane C
color (upper /down side)	yellow/black	orange/black	grey
thickness (mm)	1.5 (EN 1849-2)	2.0 (EN 1849-2)	3.0 (EN 1849-2)
density (g/m^3)	-	-	1.25 (EN ISO 1183-1)
mass per unit area (g/m^2)	1950 (EN 1849-2)	2740 (EN 1849-2)	-
tensile strength at break (kN/m)	22.5 (EN 12311-2)	30 (EN ISO 527-1 e 3, specimen type 5, 100 mm/min)	30 (EN ISO 527-4, 100 mm/min)
elongation et break (%)	300 (EN 12311-2)	250 (EN ISO 527-1 e 3, specimen type 5, 100 mm/min)	250 (EN ISO 527-4, 100 mm/min)
tear strength (kN/m)	-	≥ 45 (ISO 34, method B, 500 mm/min)	≥ 130 (ISO 34, method B, 500 mm/min)
foldability at low temperature	-	pass without cracks, fissures at -25º C (EN 495-5)	pass without cracks, fissures at -30º C (EN 495-5)

2.2 *Thermal seam preparation*

The dual track thermo-fusion seams used in this study were made by each supplier, using a hot air welder machine. From each geomembrane sample, specimens were cut, with the dimensions of 25 mm wide and 150 mm long, with the seam located in the middle (Figure 1).

These specimens were placed in a constant temperature room at 12 different temperatures: 5, 7, 10, 14, 16, 20, 23, 27, 30, 33, 37 and 41ºC, for 40 hours, before testing.

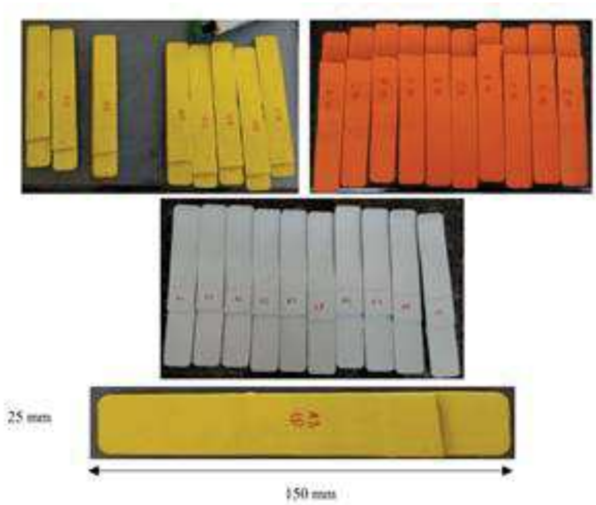

Figure 1. Specimens overview (Sanfona, 2018)

2.3 *Testing procedure*

The seams of the three geomembranes were evaluated by peel tests at 50 mm/min, according to ASTM D 6392, using a Leister EXAMO 300F machine (Figure 2). Both tracks of dual track fusion seam were tested. In brief, a total of 360 tests (5 specimens for each sample) were conditioned for 40 h, in a constant temperature room, at 11 different temperatures: 5, 7, 10, 14, 16, 20, 27, 30, 33, 37 and 41 ºC, in addition to that indicated by the standard (23 ºC). The peel strength and the locus-of-break code (Figure 3) were recorded, because some acceptance criteria require that the specimens meet a specified minimum peel strength value or break with an FTB (film-tear bond); that is, all of the tested specimens must break at the seam edge (SE) or in the sheeting outside the seam area (BRK). Adhesion failure is not acceptable either.

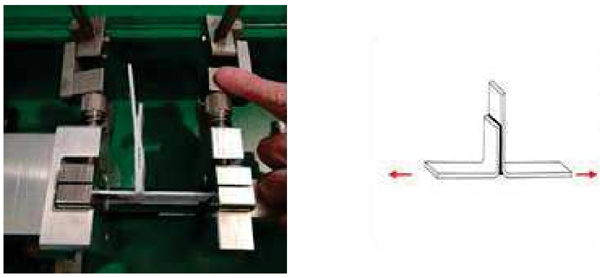

Figure 2. Example of a peel test for seamed geomembrane C

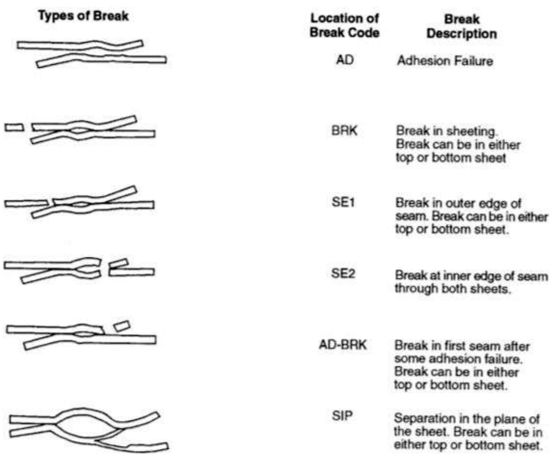

Figure 3. Locus-of-break codes for dual track fusion seams (according to the ASTM D 6392)

A minimum peel strength of 2.6 kN/m is often suggested for field seams of PVC geomembranes up to and including 1.0 mm thicknesses. The recommended criterion for factory-fabricated seams is an FTB or a peel strength greater than 3.5 kN/m (Haxo & Kamp, 1990).

Testing a seam in the peel mode supplies information as to the quality of the adhesion and the integrity of the seam. Testing in the shear mode of a seam specimen provides information only as to how the membrane was affected by the seaming process, e.g. buffing, damage and overheating. It does not provide information as to the integrity of the seam and the completeness of the bonded area across the seam (Peggs, 1990). Thus, it was decided to carry out only shear tests for one of the three geomembranes (geomembrane C).

The seams of the geomembrane C were evaluated by shear tests (Figure 4) at 100 mm/min, and not at 500 mm/min according to ASTM D 6392, because the range of testing speed of the Leister EXAMO 300F machine is just 2.5 mm/min – 300 mm/min and it is important to carry out these tests with the same machine used for testing field seams. To have an idea about the impact of the speed on test results, preliminary tests were carried out with two different speeds, using a constant machine cross head speed: 20 specimens were tested with a speed of 100 mm/min and 20 specimens with a speed of 500 mm/min. Results of these tests showed that shear strength was approximately 3 kN/m higher, when tests were carried out at 500 mm/min.

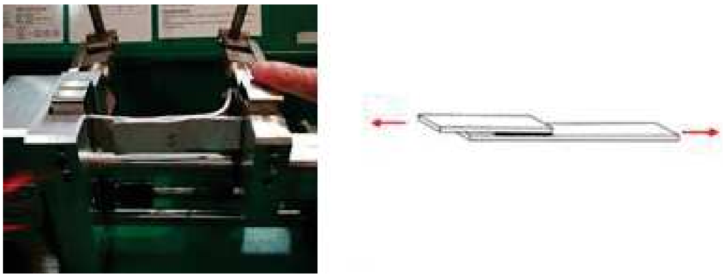

Figure 4. Example of shear test for seamed geomembrane C

A total of 60 tests (5 specimens for each sample) were carried out in a constant temperature room at 11 different temperatures: 5, 7, 10, 14, 16, 20, 27, 30, 33, 37 and 41 ºC, besides the 23 ºC indicated on the standard. The shear strength, and the locus-of-break code were recorded, because some acceptance criteria require that the specimens meet a specified minimum shear strength value and to break with an FTB. A minimum shear strength of 14 kN/m is often suggested for field seams of PVC geomembranes with1.0 mm thickness and 20 kN/m for PVC geomembranes with 1.5 mm thickness (FGI, 2017). Regarding the thicker geomembranas, to the authors' knowledge, there is no general criteria.

Other authors (e.g. Rohe, 2011) refer that an important difference between PVC and HDPE seam testing is that failure does not have to occur in the PVC sheet on either side of the seam (FTB). FTB is the requirement that the bond of the seam is stronger than the parent film and the film itself fails before the seam fails. This requirement applies to high density polyethylene (HDPE) films because they have such a small window of functional elongation. When the HDPE material only elongates 50% before it breaks, it's very important that the seam never comes apart. PVC geomembrane has a completely different molecular structure which gives it excellent elongation properties. While the PVC material does thin out as it is elongated, it does not exhibit any yield point typical with polyethylene. At 200% elongation the 1.0mm PVC geomembrane did not exhibit any failures in peel or shear mode. PVC only requires that the shear and peel strengths exceed a minimum specified value.

The locus-of-break codes are beyond the aim of this study and therefore will not be discussed in the current work.

3 RESULTS AND DISCUSSION

3.1 *Effect of test temperature on seam peel strength*

Regarding peel strength, Figures 5, 6 and 7 present the effect of test temperature obtained for the seams of geomembranes A, B and C respectively. The peel strength values correspond to the average of the five test specimens tested. The graphs also include the error bars corresponding to the standard deviation.

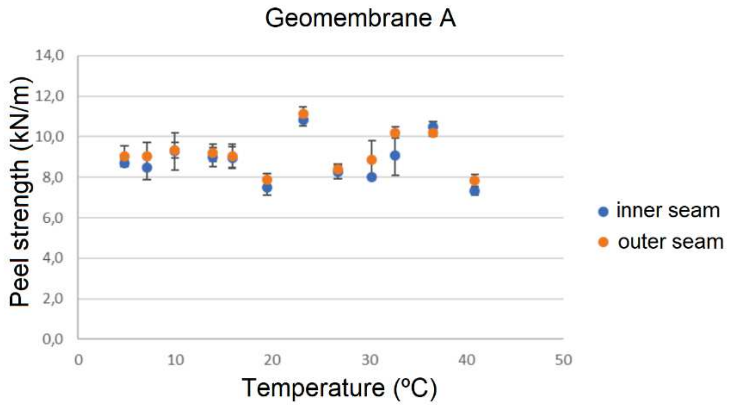

Figure 5. Geomembrane A: effect of test temperature on seam peel strength (Sanfona, 2018)

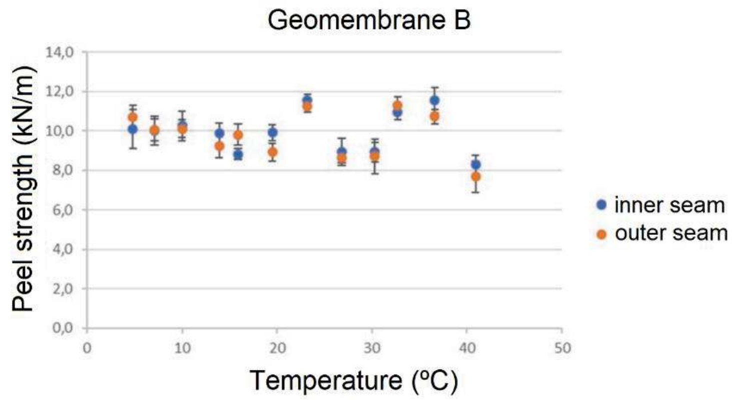

Figure 6. Geomembrane B: effect of test temperature on seam peel strength (Sanfona, 2018)

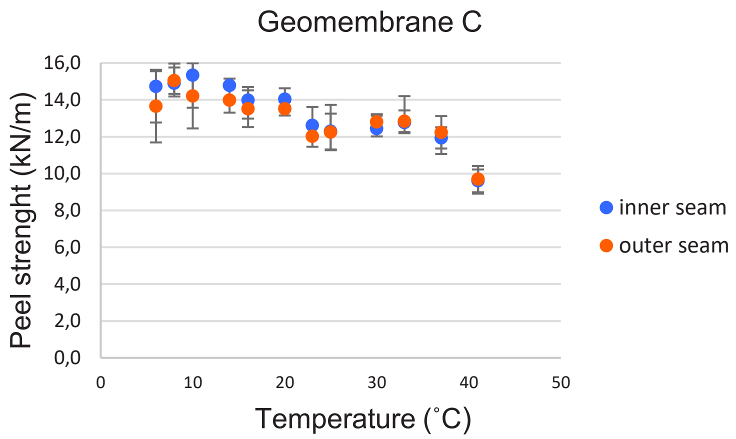

Figure 7. Geomembrane C: effect of test temperature on seam peel strength

For the three geomembranes, the peel strength values obtained were relatively constant with temperature variation (not exceeding a variation of 5 kN/m), suggesting that the test temperature does not have a significantly influence. These results are very different from those obtained in a similar study carried out for 2 mm HDPE geomembranes by Lopes *et al.* (2006).

Figure 8 shows the results obtained for HDPE geomembranes and geomembrane B (the only one in this study with 2 mm thick).

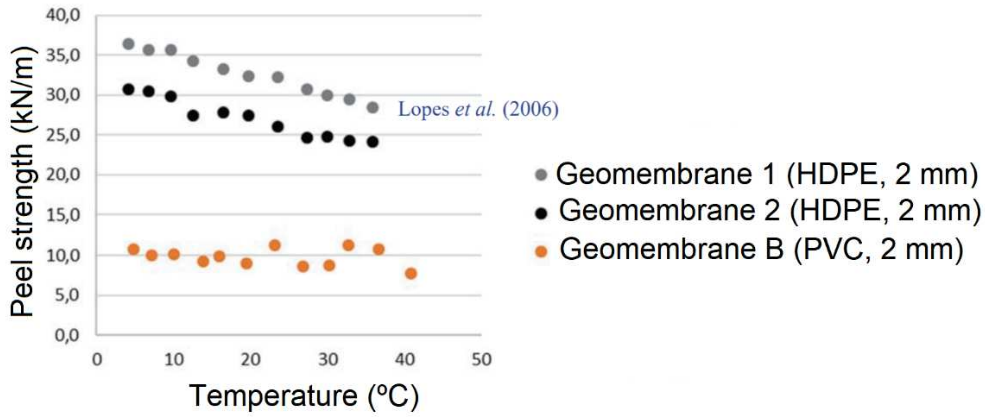

Figure 8. Effect of test temperature on seam peel strength for PVC and HDPE geomembranes

The results show that peel strength of HDPE geomembranes seams varies over a range values between 24 kN/m and 36 kN/m, significantly higher than the range obtained for the peel strength of PVC geomembrane seams (between 8 kN/m and 12 kN/m).

3.2 *Effect of test temperature on seam shear strength*

Regarding shear strength, Figure 9 presents the effect of test temperature obtained in this study for the seams of geomembrane C. The shear strength values correspond to the average of the five test specimens tested. The graph also includes the error bars corresponding to the standard deviation.

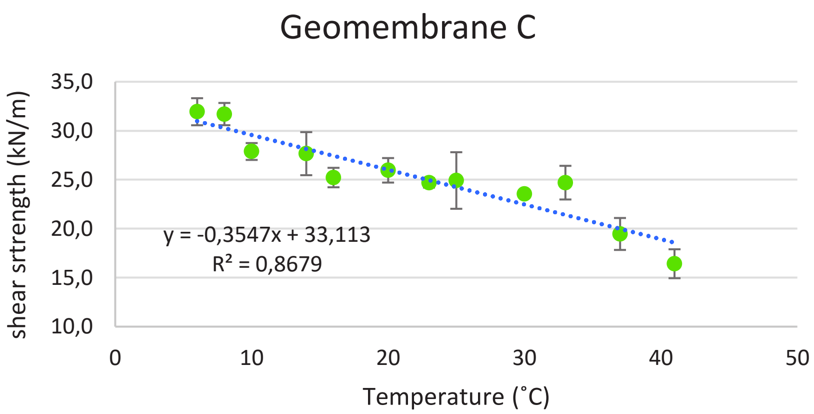

Figure 9. Geomembrane C: effect of test temperature on seam shear strength

The results show a significant (linear) decrease in shear strength with increasing test temperature. A decrease was also verified (Figure 10) in a similar study carried out for 2 mm HDPE geomembranes (Lopes & Lopes, 2001).

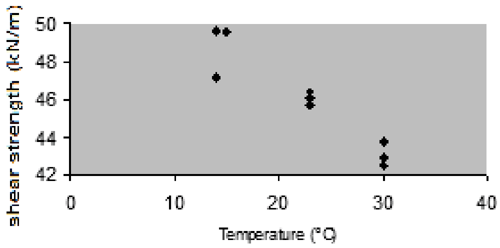

Figure 10. Effect of test temperature on seam shear strength for 2 mm HDPE geomembranes (Lopes & Lopes, 2001)

4 CONCLUSIONS

In this work, the influence of test temperature on the peel and shear strength of PVC geomembrane seams was studied. This issue is important because, sometimes in the field, it is not possible to carry out these tests at the standard temperature of 23ºC (± 2ºC), raising questions on their acceptance/rejection.

The results showed that test temperature has small influence on the peel strength values of the PVC geomembrane seams, contrary to what happens with HDPE geomembranes.

Results also showed a significant decrease in shear strength with increasing test temperature, as was also verified with HDPE geomembranes. Thus, field shear tests performed at low temperatures may give inaccurate results, once they may show that seam strength is satisfactory when it is not.

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REFERENCES

ASTM D 6392 (2018) *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.

FGI (Fabricated Geomembrane Institute) (2017) PVC Geomembrane Material Specification 1117. University of Illinois, Urbana, IL.

Haxo, H. E. and Kamp L. C. (1990) Destructive testing of geomembrane seams: Shear and peel testing of seam strength. *Geotextiles and Geomembranes*, vol 9, issues 4-6, 369–395.

ICOLD (2010) Geomembrane sealing systems for dams. *Bulletin 135 of the International Commission on Large Dams*, Paris, France.

Lopes, M. G. and Lopes M. L. (2001) Portuguese experience in construction of municipal solid waste landfill liner systems. *Proceedings of 15th International Conference of Soil Mechanics and Geotechnical Engineering*, 27 - 31 August, Istanbul, Turkey.

Lopes, M. G., Barroso, M. and Costa, C. (2006) Acceptance criteria for HDPE geomembranes double hot wedge seams: influence of the temperature on peel strength. *Proceedings of 8th International Conference on Geosynthetics*, 18 - 22 September, Yokohama, Japan.

Peggs I. D. (1990) Destructive testing of polyethylene geomembrane seams: Various methods to evaluate seams strength. *Geotextiles and Geomembranes* Nº. 9 (4), pp. 405-414.

Rohe, D. S. (2011) PVC Geomembrane Research Negates Film Tearing Bond Requirement. *Geo-Frontiers Congress 2011, March 13-16 Dallas, U.S.*

Sanfona, P. (2018) *Aplicação de Geomembranas de PVC em Barragens: Influência da Temperatura no Controlo das Soldaduras*. Master's thesis. Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa, Lisbon.