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PVC geomembrane seams: Influence of the testing speed on peel and shear test results

M. Barroso
Laboratório Nacional de Engenharia Civil, Lisbon, Portugal

M.G. Lopes
Instituto Superior de Engenharia de Lisboa, Lisbon, Portugal

ABSTRACT: The PVC geomembranes are the most commonly used in dams. The success of geomembranes as barrier depends on field seams quality. Seams have to be evaluated in terms of continuity and mechanical strength, the latter being assessed by peel and shear tests. These tests are generally carried out according to the ASTM D 6392, which, for PVC geomembranes, recommends a testing speed of 50 mm/min, for peel test, and 500 mm/min, for shear test. However, in field, sometimes it is not possible to attain the testing speed suggested for shear test. This raises questions about the acceptance of seams. To address this issue, two thermally bonded PVC geomembrane seams were tested to peel and shear strength at testing speeds ranging from 50 to 500 mm/min. The results showed that shear and peel strengths tend to increase with the testing speed.

1 INTRODUCTION

Geomembranes have been applied to dams since the 1950s. In the first applications, a wide variety of geomembranes were used. Then, based on experience acquired in early applications, as well as developments in research, testing and manufacturing, the best performing geomembranes have progressively become more popular (Cazzuffi *et al.* 2010). Currently, polyvinyl chloride (PVC) geomembranes are the most commonly used in dams (ICOLD 2010).

The performance of geomembranes as barriers in dams depends on field seams quality. PVC geomembrane field seams are typically made by thermal fusion (hot air or hot wedge). For that it is necessary to melt the polymer at the sheet surface using a heat source. The heat can be transferred to the sheets to be welded from hot air or a hot wedge. A hot air welder uses an air blower that blows heated air from an electrical element between the two sheets to be bonded by melting an interface strip. A hot wedge welder generates the heat energy necessary to melt the sheets at the interface by electrical elements placed directly between two sheets. Pressure is applied to the top and/or bottom sheets of the geomembrane, forcing together the two surfaces to form a continuous bond (Stark *et al.* 2004).

Dual-track and single-track seams can be made. Both types of seams allow destructive and non-destructive testing to assess seams quality in terms of continuity and mechanical strength.

Mechanical strength is typically evaluated based on peel and shear tests. For PVC geomembranes thicker than 1.5 mm, these tests are generally carried out according to ASTM D 6392 standard, which recommends a testing speed of 50 mm/min, for peel test, and 500 mm/min, for shear test. However, in field, sometimes it is not possible to attain the testing speed

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suggested for shear test, mainly due to limitations of the testing machines routinely used. This raises questions about the acceptance of seams.

To address this issue, two thermal fusion seams were tested to peel and shear strength at testing speeds ranging from 50 to 550 mm/min, based on test procedure described in the ASTM 6392 standard.

The locus-of-break codes of the seams, according the same ASTM standard, were also addressed in order to discuss its usefulness within the acceptance criteria for PVC geomembranes.

2 EXPERMENTAL WORK

2.1 *Materials*

Two commercially available PVC geomembranes were used in this study, hereafter referred to as geomembrane A (1.5 mm thick) and geomembrane B (2.0 mm thick). Their main properties are summarized in Table 1, according to Technical Data Sheets provided by the supplier.

Table 1. Main geomembranes properties based on technical data sheets.

Property	Geomembrane A	Geomembrane B
Color (upper /down side)	orange/black	orange/black
Thickness (EN 1849-2)(mm)	1.5 (-5/+10%)	2.0 (-5/+10%)
Mass per unit area (EN 1849-2) (g/m^2)	2055 (-5/+10%)	2740 (-5/+10%)
Tensile strength at break (EN ISO 527-1 and 3, specimen type 5, 100mm/min) (kN/m^2)	$\geq 1.5\times10^4$	$\geq 1.5\times10^4$
Elongation at break (EN ISO 527-1 and 3, specimen type 5, 100 mm/min) (%)	$\geq$250	$\geq$ 250
Tear resistance (ISO 34, method B, 500mm/min) (kN/m)	$\geq$ 45	$\geq$ 45
Puncture resistance (EN ISO 12236) (kN)	2 ($\pm$0.25)	2.3 ($\pm$0.25)
Foldability at low temperature (EN 495-5)	Not failure at -25ºC	Not failure at -25ºC

Dual-track seam samples, welded by hot air, were made from geomembranes A and B. From each seam sample, specimens were cut such that the seams were perpendicular to the longer dimension of the strip sample. Specimens were die cut using a 25 mm wide by 150 mm long die. (Figure 1).

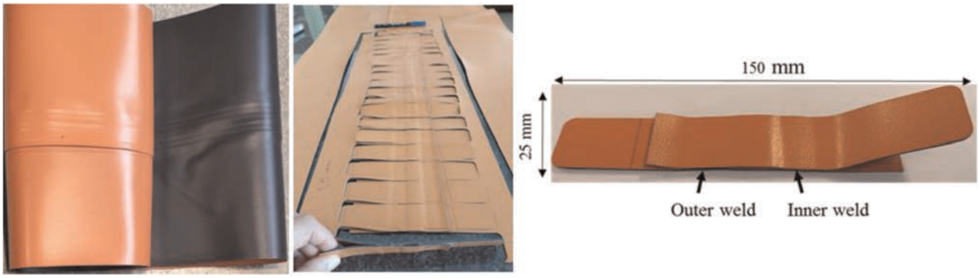

Figure 1. Dual-track geomembrane seam sample and seam specimen.

2.2 *Testing procedure*

Tests were carried out based on the ASTM D 6392, but at different testing speeds of besides the one indicated in this standard, 50 mm/min, for peel test, and 500 mm/min, for shear test.

The ASTM D 6392 standard was used rather than ASTM D 7408 since the latter covers just PVC geomembranes in thickness of 0.25 through 1.52 mm.

Testing speeds used were as follows: 50, 100, 150, 200, 250, 300, 350, 400, 450, 500 and 550 mm/min.

Although on ASTM standard recommends to test five specimens to peel and five specimens to shear, in this study, for each testing speed, twenty specimens were tested to shear and ten specimens were tested to peel. A smaller number of specimens were tested to peel because the length of the sample did not allow to cut a larger number of specimens.

Specimens were pulled out as shown in Figure 2, for peel and shear test, respectively. In peel test, inner and outer welds were tested from outside towards the air channel.

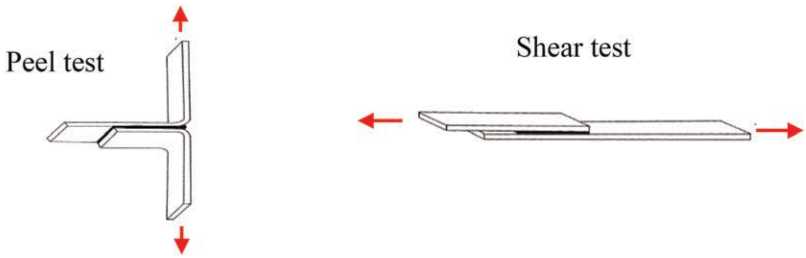

Figure 2. Scheme of the peel and shear test.

In total, 880 tests were carried out: 440 peel (10 specimens×11 testing speeds×2 welds×2 geomembranes) and 440 shear tests (20 specimens×11 testing speeds×2 geomembranes).

Minimum values of peel strength and shear strength of 2.6 kN/m and 20kN/m, respectively, are typically required for field seams of PVC geomembranes up to 1.5 mm thick (FGI 2017). For thicker geomembranes, to the best of the authors' knowledge, there are no general acceptance criteria.

In addition to peel and shear strengths, locus-of-break codes, as per their description in ASTM D 6392 (Figure 3), were recorded. Typically, AD and AD BRK break > 25% codes are unacceptable, in peel and shear modes.

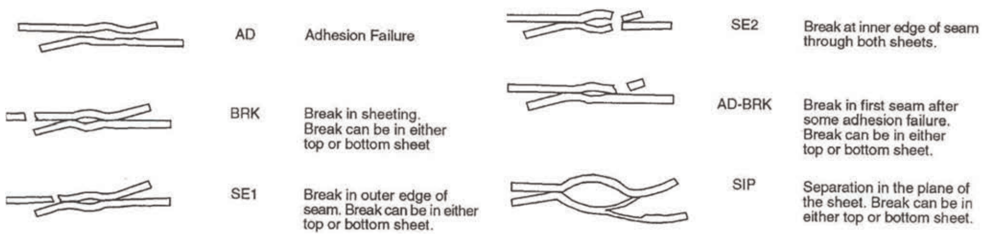

Figure 3. Locus-of-break codes for seam strength in shear and peel modes (ASTM D 6392).

3 RESULTS AND DISCUSSION

3.1 *Influence of the testing speed on shear strength*

Figures 4 and 5 present the results of shear strength as function of testing speed, for geomembranes A and B. The shear strength values correspond to the average of the 20 test specimens tested, per each testing speed.

Graphs contain error bars corresponding to the standard error. The standard error value was calculated from the standard deviation expanded to a confidence level of 95%, using the t-Student distribution. In the discussion presented below, it is assumed that differences in tests results are only significant when they are higher than the standard errors associated with the measurements.

Results depicted in Figures 4 and 5 show that shear strength tends to increase as testing speed increases from 50 to 550 mm/min. The increase was 3.2 kN/m, for geomembrane A, and 3.3 kN/m, for geomembrane B.

Results obtained in this study are consistent with the results reported by Lopes & Barroso (2022). These authors tested a PVC geomembrane seam (2.5 mm thick) at testing speeds of

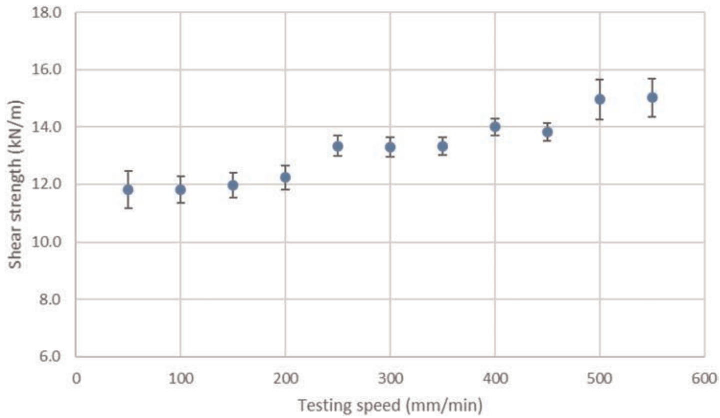

Figure 4. Geomembrane A (1.5 mm): Effect of testing speed on seam shear strength.

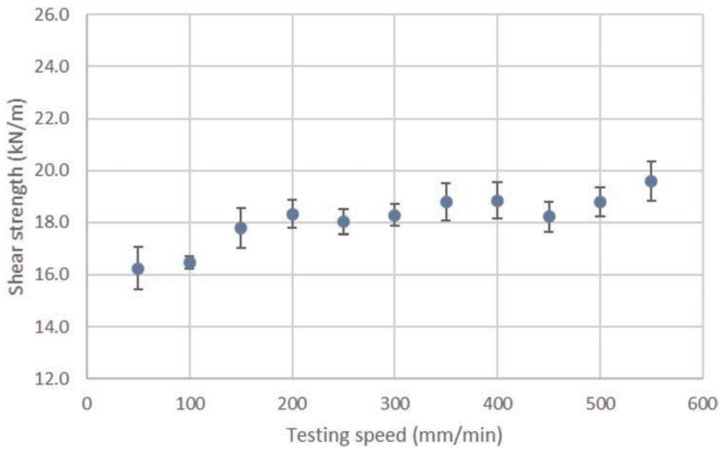

Figure 5. Geomembrane B (2.0 mm): Effect of testing speed on seam shear strength.

100 mm/min and 500 mm/min. They tested 40 specimens, 20 at a testing speed of 100 mm/min and 20 at a testing speed of 500 mm/min, using a constant machine cross head speed. They found that shear strength was, approximately, 3.0 kN/m higher for testing speeds of 500 mm/min.

For geomembrane A, shear strength of dual-track seam ranged from 11.8 kN/m and 15.0 kN/m. These values are significantly lower than the minimum of 20.0 kN/m suggested on acceptance criteria by FGI (2017), raising questions about the seam quality.

For geomembrane B, shear strength ranged from 16.3 and 19.6 kN/m. These values are not compared with acceptance criteria proposed by FGI (2017), as they include only geomembranes up to 1.5 mm thick.

3.2 *Influence of the testing speed on peel strength*

Regarding peel strength, Figures 6 and 7 present the effect of testing speed obtained for the seams of geomembranes A and B, respectively. The peel strength values correspond to the average of the 10 test specimens tested, per each testing speed. As for shear strength, graphs also include the error bars corresponding to the standard error.

Peel strength shows a slight increase with the increase of the testing speed from 50 to 550 mm/min, for geomembranes A and B. This happens for both welds (inner and outer).

Geomembrane A shows systematically higher peel strength in the outer weld than in inner weld. This trend does not occur for geomembrane B, inner and outer welds presented similar strengths.

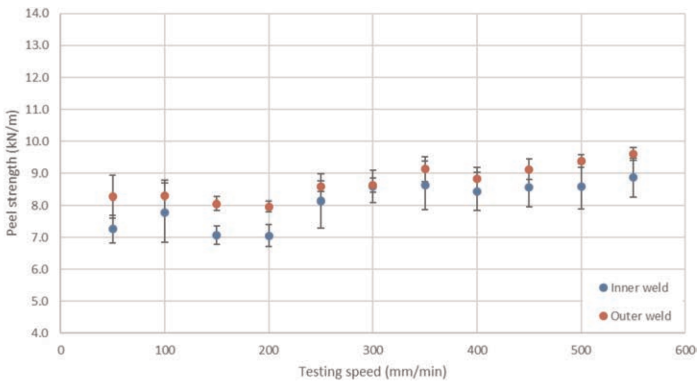

Figure 6. Geomembrane A (1.5 mm): Effect of testing speed on seam peel strength.

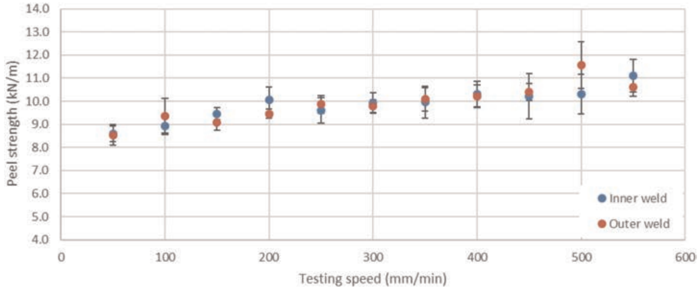

Figure 7. Geomembrane B (2.0 mm): Effect of testing speed on peel shear strength.

Taking into account the standard error estimated, results obtained suggest that testing speed has a small influence on peel strength.

For geomembrane A, results obtained for peel strength of dual-track seam ranged from 7.1 kN/m and 8.9 kN/m, for inner weld, and ranged from 8.0 kN/m and 9.6 kN/m, for outer weld. These values are significantly higher than the minimum of 2.6 kN/m suggested on acceptance criteria of FGI (2017), which raises questions about the suitability of the value required as a minimum.

For geomembrane B, peel strength ranged from 8.6 kN/m and 11.1 kN/m, for inner weld, and ranged from 8.5 kN/m and 11.6 kN/m, for outer weld. Minimum values for geomembranes thicker than 1.5 mm are not included in criteria by FGI (2017).

3.3 *Locus-of-break codes for the peel and shear modes*

Locus-of-break codes for the peel (inner and outer welds) and shear modes as per their description in ASTM D 6392 (see Figure 3), were recorded for each specimens.

Table 2 summarizes the results obtained in peel test. In shear test, all specimens exhibited SE break. This means that the 440 tested specimens exhibited SE break.

As can be seen in Table 2, most of the breaks were type SE (break in outer or in inner edge of the seam). A large number of AD breaks were also obtained. Regarding the SIP breaks, it was found that the separation occurred at the interface between the two layers that comprise the geomembrane, distinguished by different colors (orange and black).

Table 2. Locus-of-break codes for seam strength peel mode (based on ASTM D 6392).

	Geomembrane A*		Geomembrane B*	
Locus-of-break codes	inner weld	outer weld	inner weld	outer weld
AD	34	–	51	11
BRK	–	–	–	–
SE1	73	107	54	80
SE2	–	–	–	–
AD-BRK	–	–	–	–
SIP	3	–	5	–

* For some specimens it was impossible to fully grip them across its width. For geomembrane A, 217 of 220 specimens were tested; for geomembrane B, 201 of 220 specimens were tested.

The usefulness of break type analysis for PVC geomembranes has been questioned by several authors. For example, Rohe (2011) refer that an important difference between PVC and high density polyethylene (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 HDPE films because they have such a small window of functional elongation. When the HDPE material only elongates 50% before it breaks, it is 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 1.0 mm 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.

Results obtained in this study tend to confirm that the type of rupture does not provide additional useful information about the quality of seams. Thus, its usefulness raises some doubts. However, due to the limited number of PVC geomembranes tested, more research is necessary to confirm this judgment.

4 CONCLUSIONS

In this work, the influence of testing speed on peel and shear strength of PVC geomembrane seams was studied. This issue is important because, in field, it is not always possible to carry out these tests at the standard testing speed, raising questions on their acceptance.

The results showed that shear and peel strengths tend to increase with the testing speed. However, the increase of testing speed has higher impact on shear strength than on peel strength. More research seems to be necessary to confirm this trend.

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REFERENCES

ASTM D 6392. 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.

Cazzuffi, D.A., Giroud, J.P., Scuero, A. & Vaschetti, G. 2010. Geosynthetic Barriers Systems for Dams. *9th International Conference on Geosythetics*, Guarujá, Brazil, 23-27 may 2010, pp. 115–163.

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

ICOLD 2010. Geomembrane Sealing Systems for Dams. *Bulletin 135 of the International Commission on Large Dams*, Paris, France.

Lopes, M.G. & Barroso, M. 2022. PVC Geomembranes in Dams: Influence of Test Temperature on Seams Peel and Shear Strength. *7th European Geosynthetics Conference*, EuroGeo7, Warsaw, Poland, 4-7 september2022, pp. 795–802.

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

Sanfona, P.; Barroso, M. & Fontul, S. 2019. Influência da Temperatura no Controlo Das Soldaduras de Geomembranas de PVC. *Revista Geotecnia No 147*, Novembro 2019; pp. 3–13; http://doi.org/10.24849/j.geot.2019.147.01 (in Portuguese).

Stark, T. D., Choi, H. & Thomas, R. W. 2004. Low Temperature Air Channel Testing of Thermally Bonded PVC Seams. *Geosynthetics International*, 11, No. 6, 481–490.