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Influence of the Test Method on Tensile Properties of Thin Polymeric Geosynthetic Barriers

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ABSTRACT
Several engineering applications employing polymeric geosynthetic barriers need to have their tensile properties determined with confidence, according to standard test procedures that do not allow erroneous interpretations and decisions. However, there is no consensus on the standard test indicated to determine the tensile behavior of thin geomembranes in several recommendations and specifications in use. The paper compares the procedure adopted by American, International and Brazilian standards, and the results obtained in tests with PVC and fPP thin geomembranes. ABNT NBR 15826 and ISO 527-3 have the same procedure and present the most reliable results. ASTM D882 presents results closed with ISO results but with a lightly greater dispersion. ASTM D6693 presents a large dispersion of the results, and significant differences in percent elongation at break, with results 40% lower than ISO 527-3.

RESUMO
Várias das aplicações de engenharia que empregam barreiras geossintéticas poliméricas precisam ter as propriedades de resistência à tração destes produtos determinadas com confiança, obedecendo a procedimentos de ensaio padrão que não permitem interpretações e decisões errôneas. No entanto, não há consenso sobre o ensaio padrão indicado para determinar o comportamento sob tração de geomembranas pouco espessas, nas várias recomendações e especificações em uso. O artigo compara o procedimento adotado pelas normas americanas, internacionais e brasileiras, e os resultados obtidos em ensaios em geomembranas pouco espessas de PVC e fPP. A ABNT NBR 15826 e a ISO 527-3 têm o mesmo procedimento e apresentam os resultados mais confiáveis. A ASTM D882 apresentou resultados próximos dos resultados da ISO, mas com dispersão um pouco maior. A ASTM D6693 apresenta uma grande dispersão dos resultados, e diferenças significativas no alongamento na ruptura, com resultados 40% menores do que os obtidos pela ISO 527-3.

1. INTRODUCTION

Geotechnical and environmental engineering projects employ thin polymeric geosynthetic barriers in dams, canals, reservoirs and disposal areas of solid or liquid waste. Thin geomembranes are present in biodigesters roofing systems and reservoirs, or in waterproofing systems in areas with low environmental risk. Thin thickness products are also being used in systems with sealing devices containing two or more flow barrier elements (ASTM D7176).

So that these products meet the design needs and specifications, their tensile strength characteristics should be assessed during the manufacturing process and during the product acceptance phase in the field (EN 13493, IGSBrasil 002-2, ABNT NBR 16757-2). Furthermore, it is the analysis of the tensile properties the tool usually chosen to evaluate the behavior of these membranes over time, considering the various agents that could degrade it (weathering, chemical attack, oxidation, ...) (ISO 4582, ISO/TS 13434, Rowe and Sangam 2002).

Tensile strength properties being of high importance for the identification, characterization and quality control of the products, it is essential that manufacturers, researchers, designers and responsible for quality control, disposal of testing standards whose suitability and repeatability were well evaluated in order to provide values that allow the comparison between products and facilitate the quality and durability controls.

The quality and type of polymer component, the quality and dosage of additives used, and the manufacturing process influence the tensile strength properties asking for control tests. Therefore, a clear definition of procedures becomes necessary when considering that these properties are also affected by factors related to the test. Aspects as the sample thickness, test specimen preparation mode, tensile speed, distance between grips, type of grips and the system adopted for elongation measurement, can influence the results.

The characteristic properties associated with the behavior under tensile (tensile strength and elongation at break) are essential for the use of geomembranes in engineering projects, is set as a minimum requirement for all applications. The recommendations and standards published for the quality control and specification of polymeric geosynthetic barriers (EN 13361, EN 13362, EN 13492, EN 13493, IGSBrasil 002-2, NBR 16757-2, GRI test Methods GM 13 and GM18) are widely used by manufacturers and designers. However, there is no consensus on the standard test to be employed in tensile behavior determination, so that test methods producing different results can lead to conflicts and difficulties for the acceptance or rejection of a particular product.

Although some experts warn for years about the need for equivalent test methods (Gourc et al. 1986, 1990), almost there are no recent discussions about the influence of different procedures on the obtained parameters. Thus, this article aims to present a comparative analysis of tensile on performance evaluation of the results obtained in testing considering the testing standards set out in the recommendations and most frequently used specifications for thin geomembranes. For this, results of tests conducted on samples of polymeric membranes composed by flexible polyvinyl chloride (PVC-P), and flexible polypropylene (fPP), according to American standards (ASTM), Brazilian standards (ABNT) and International standards (ISO) are presented and their variability evaluated.

2. RECOMMENDATIONS AND TEST METHODS

Table 1 resumes the recommendations and specifications commonly employed in manufacturing and quality control for polymeric geomembranes and thin plastics. As can be seen, different standards are requested to evaluate the tensile properties of these materials: ASTM D6693, ISO 527-3, ABNT NBR 15856 and ASTM D882. ASTM 7176 recommends the test method described in ASTM D882 to PVC-P geomembranes up to 1.5mm. Therefore, ASTM D882 was conceived for thin films (<1.0mm) and this standard recommends to employ ASTM D638 for plastics 1.0 mm or greater in thickness.

Table 1. Recommendations for use of geomembranes in several applications.

Specification/ Recommendation	Description	Standards	Description
EN 13361,13362, 13492 and 13493	Characteristics required for use of geosynthetics barriers	ISO 527-3	Tensile strength characteristics for plastic films
IGSBrasil 002-2and NBR 16757-2	Characteristics required for use of geosynthetics barriers	NBR 15856	Tensile strength characteristics for geomembranes
ASTM D7176	Specification for PVC geomembranes	ASTM D882	Tensile strength characteristics for thin plastic sheeting
GRI GM13 and GM18	Geomembranes characteristics	ASTM D6693	Tensile strength characteristics for nonreinforced PE and fPP geomembranes

The main characteristics of the standards indicated in Table 1 are shown in Table 2 and Figure 1. All the standards establish that at least five specimens in each direction (machine direction, MD, and cross-machine direction, CMD) should be tested. From the analysis of the standards, it can be pointed out:

- ISO 527-3 and ABNT NBR 15856 are technically equivalent and establish that the specimens can be prepared in strip form (Type 1) or dumbbell-shaped (Type 2). It is usual to employ specimens in strip shape for geomembranes in flexible polyvinyl chloride (PVC-P) and flexible polypropylene (fPP), and dumbbells shaped for polyethylene (PE) geomembranes. The test speed is 100mm/min. For dumbbell shape specimens, the dimensions are fixed as shown in Figure 1 and the gauge length is 25mm. For strip shape specimens, the width can vary from 10 to 25mm, with 100mm between grips, and the gauge length is 50mm.

- ASTM D882 describes a test method to determine tensile properties of plastics in the form of thin sheeting and films less than 1.0 mm in thickness and can be used to test all plastics. This method is similar to ISO 527-3 but is not considered technically equivalent. The specimens have strip shape, with 25.4mm width, 50mm between grips and an optional gauge length of 25mm. The test speed is 500mm/min for elongation at break greater than 100%.

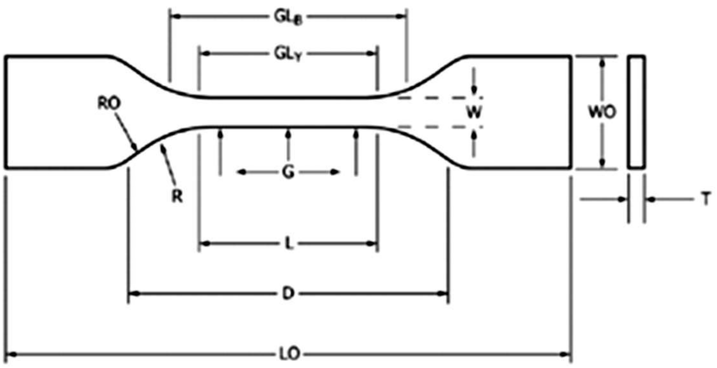
- ASTM D6693 covers the determination of tensile properties of nonreinforced geomembranes for dumbbell-shaped test specimens and can be used for testing materials thickness between 0.25mm and 6.3mm. This test method is designed to produce property data for control and specification. Therefore, Note 1 emphasizes that the method not intended to cover precise physical procedures because wide differences may exist between the rate of crosshead movement and the rate of strain of the specimen, but consider that the data obtained are relevant and may be appropriate for use in engineering design. For the dimensions and geometry of test specimens, the same conditions established in ASTM D638 – Type IV (see Fig.1) were adopted. The recommended test speed is 50mm/min for PE and 500mm/min for fPP.

- ASTM D638 describes the determination of the tensile properties of unreinforced and reinforced plastics for dumbbell-shaped test specimens and the test method is considered technically equivalent to ISO 527-1. This test method can be used for testing materials of any thickness up to 14 mm, with several structures. Type IV is the shape and test condition applied for the products considered in this work. ASTM D6693 adopts the shape and dimensions of D638, detailed in Figure 1, but this standard does not consider the special gauge length for yield or break (GLY and GLB) indicated in ASTM D6693, working with a fixed value of 25mm for gauge length. The test speed is a function of the time for rupture and the lowest speed between 5 and 500mm/min, that produces a rupture in 0.5 to 5 min, should be selected. For thin products (less than 1.0 mm in thickness), ASTM D638 considers that ASTM D882 is the preferred test method.

Table 2. Mainly characteristics of the analyzed standards.

Standard	Specimen shape	Width of narrow section (mm)	Initial distance between grips (mm)	Gauge length[a] (mm)	Speed (mm/min)
ISO 527-3 / NBR 15856	strip	10 to 25	100	50	100
	dumbbell	6	80	25	100
ASTM D882	strip	25.4	50	25	500 (if elongation >100%)
ASTM D6693	dumbbell	6	65	50	50 for PE 500 for fPP
ASTM D638	dumbbell	6	65	25	5 to 500[b]

[a] for rupture analysis; [b] the lowest speed that produces a rupture in 0.5 to 5 min



Key:

Symbol	Description	ISO 527-3/ NBR 15856 (mm)	ASTM D 6693 (mm)	ASTM D638 (mm)
W	Width of narrow section	6	6	6
L	Length of narrow section	33	33	33
WO	Width overall	25	19	19
LO	Overall length	115	115	115
D	Initial distance between grips	80	65	65
R	Small radius	14	14	14
RO	Large radius	25	25	25
G	Gauge length	25	25	25
GL_Y	Gauge length at yield	no	33	no
GL_B	Gauge length at break	no	50	no

Figure 1. Dimensions and geometry for specimens in a dumbbell shape. (adapted from ASTM D6693)

3. MATERIALS AND TESTS

For a more careful evaluation, several thin thickness products were tested: four PVC-P samples with 1.0mm in thickness (one of these being modified PVC-P), named A, B, C and D and two fPP samples with different thicknesses, sample E with 0.6mm and sample F with 0.9mm. The samples' strength was evaluated according to ASTM D882, D6693 and ISO 527 test methods for comparison purposes, even if the standard is not recommended for the polymer. Sample A was also submitted to ASTM D638 to evaluate all possible procedures.

All samples were prepared in accordance with the relevant standard test, adopting the same procedure and template for specimens of the same size and geometry. The quality of the preparation process was verified with microscopy aid, as shown in Figure 2. The images 2D were obtained with a digital microscope (Hirox KH-8700) with 35X magnification.

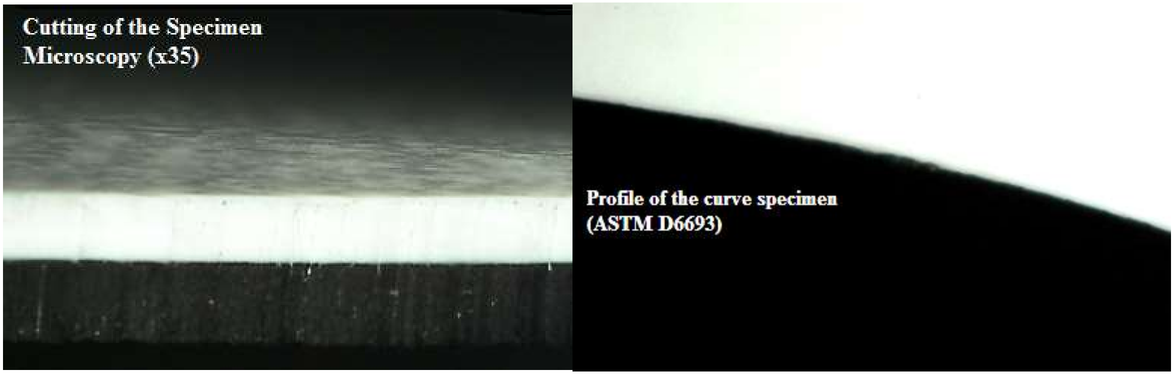


Figure 2. Examples of microscopic evaluation of specimen preparation.

Five specimens are a small number for a reasonable statistical analysis (Montgomery et al. 1987). Although ASTM D882 consider that standard deviation is not to be calculated nor reported due to the reduced number of data points, ASTM D638 and D6693 recommends calculating the average value and standard deviation. However, it is important to remember that a large number of specimens imply serious problems both for industrial quality control and to control in the field as well as the durability analysis. Thus, a testing procedure that presents a lower dispersion of results and allows considering five specimens an acceptable number is essential.

With a small number of specimens, it was necessary to assume the hypothesis of a normal distribution for statistical analysis. In this case, for a number of specimens less than 30, the estimated error can be calculated by Equation 1 and the minimum number of specimens to be tested in order to have an estimated error less than 5% is given by Equation 2 (Montgomery et al. 1987):

$$e(\%) = \left(\frac{t_{v,\propto}\,\sigma}{N^{0.5}\,X}\right) \quad [1]$$

$$N\ (\text{for } e=5\%) = \left(\frac{t_{v,\propto}\sigma}{0.05\,X}\right)^2 \quad [2]$$

being e, the estimated error, $t_{v,\alpha}$ the Student number (equal to 2.776 for 5 specimens and a level of reliability of 95%), X the data average, σ the standard deviation and N the number of specimens.

4. TEST RESULTS AND ANALYSIS

4.1 Observed values

Figures 3 and 4 present the curves obtained for the tested specimen from sample A (Fig.3), E and F (Fig.4). The first five curves in each test are related to the specimen cut in the machine direction (MD) and the last five to specimen cut in the cross-machine direction (CMD).

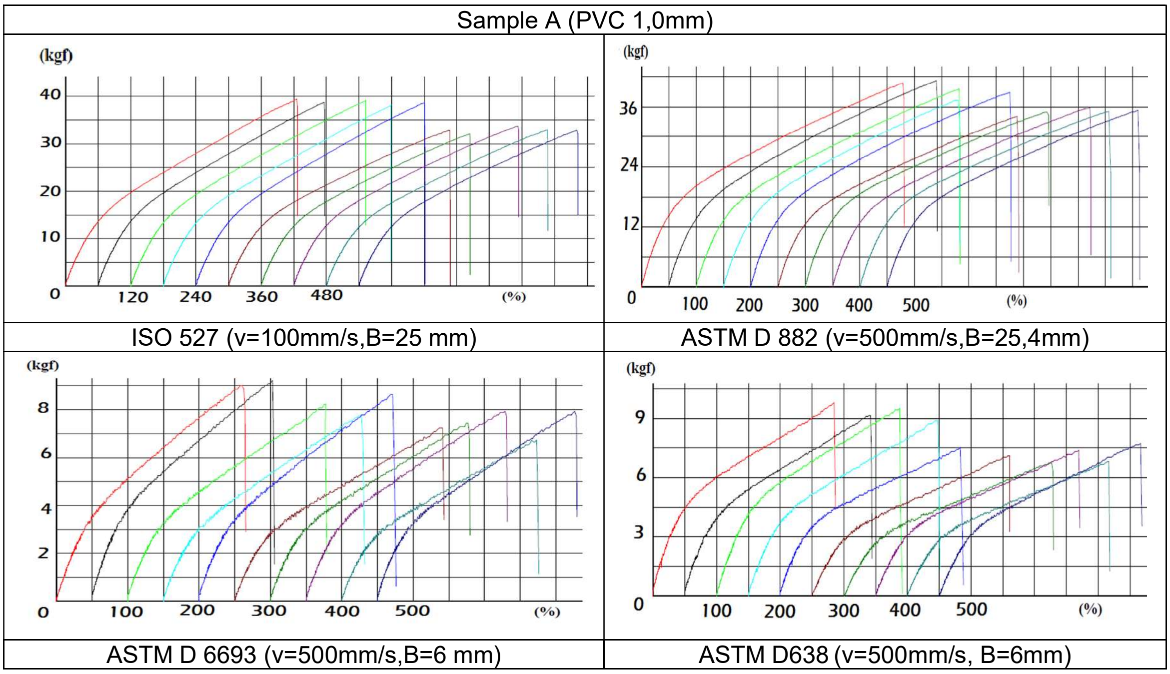


Figure 3. Tensile x strain behavior of the specimen of sample A.

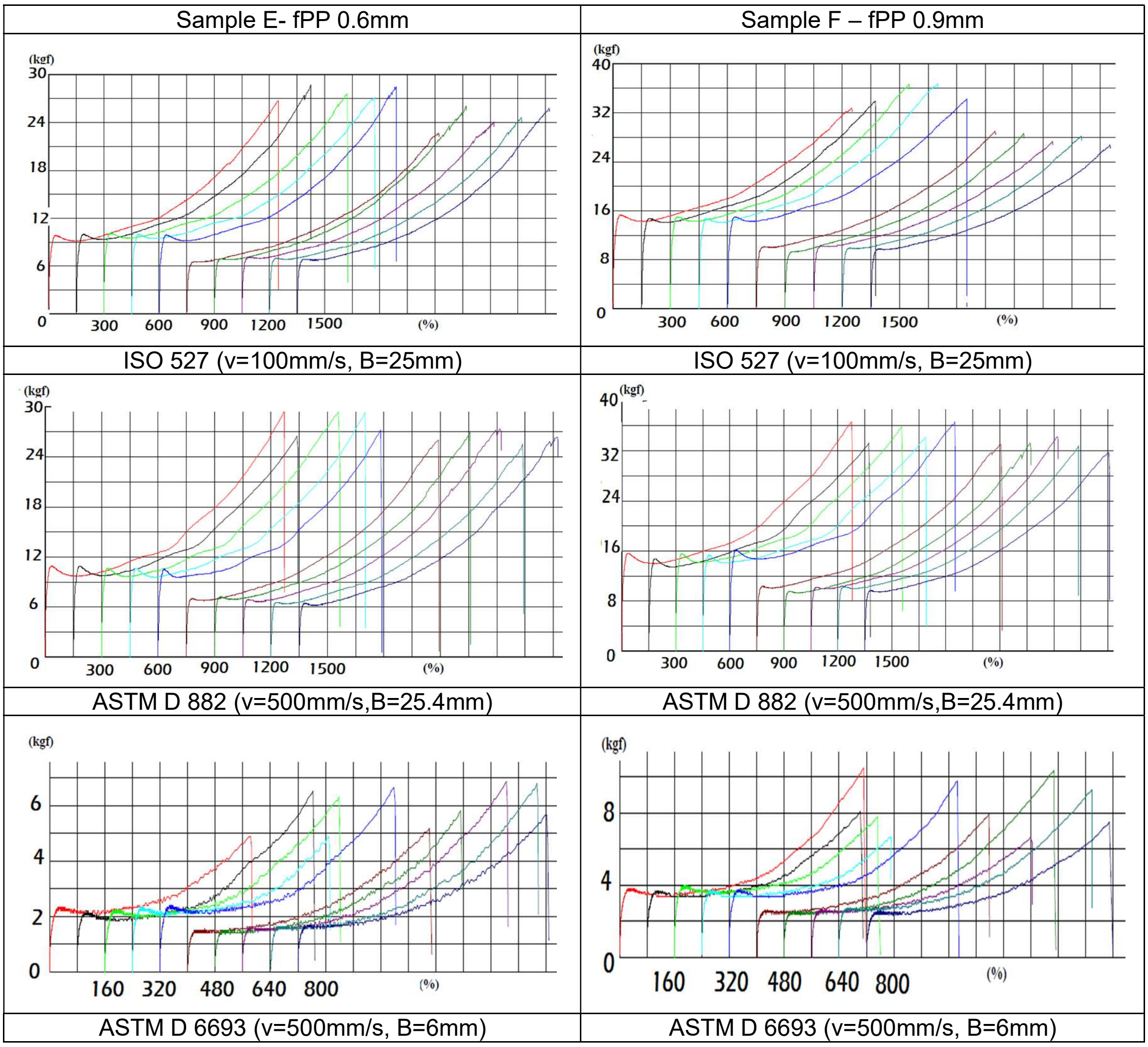
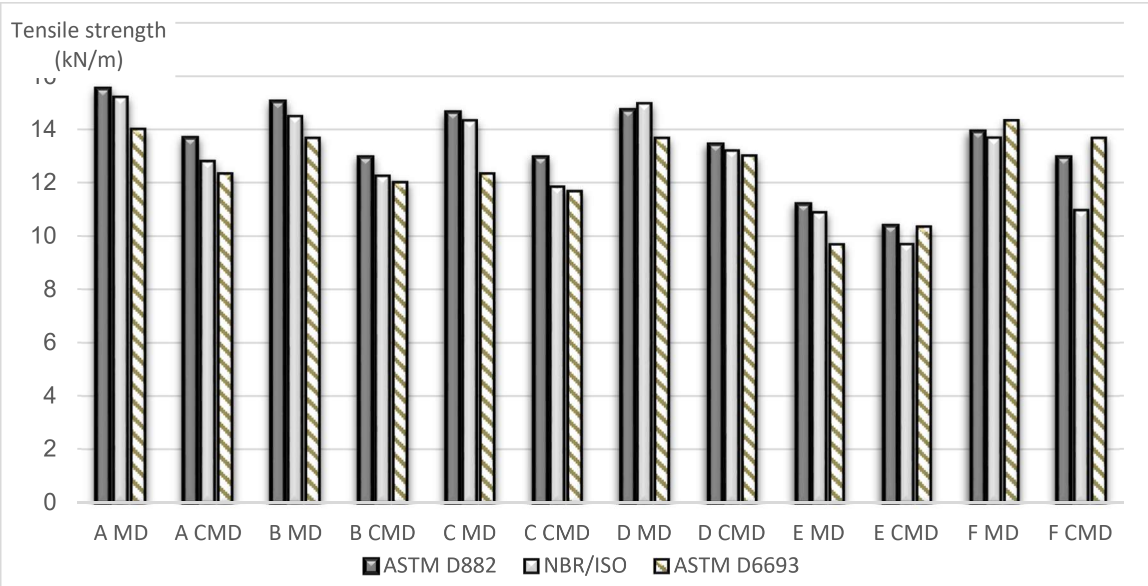


Figure 4. Tensile x strain behavior of the specimen of samples E and F.

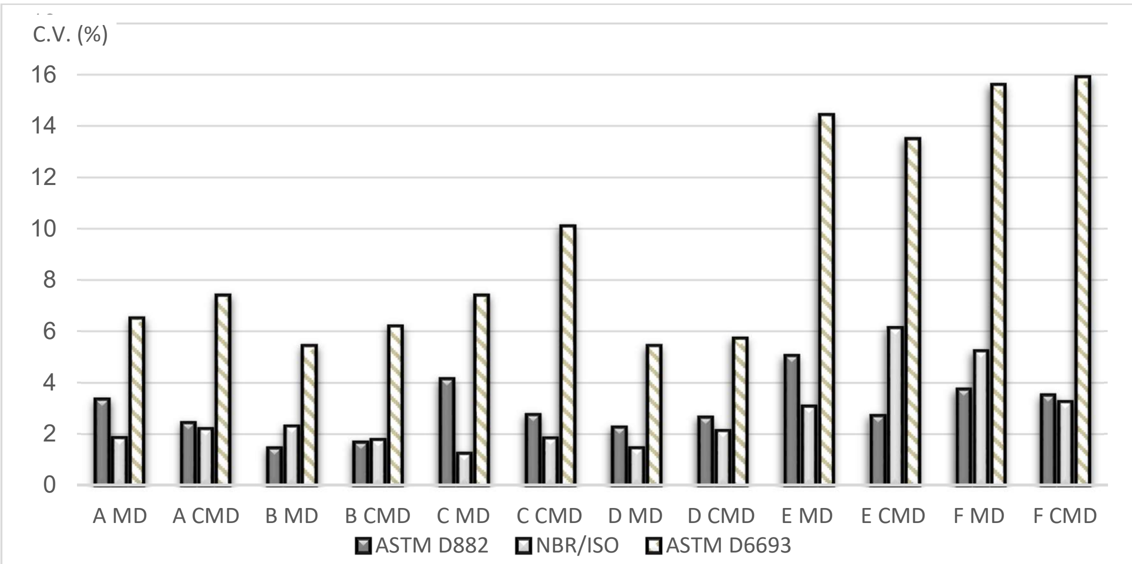
Figures 5 and 6 indicate the mean values of tensile strength at break and deformation, and the coefficient of variation, obtained from the tests conducted in the chosen materials. In these figures, A MD signifies results in the machine direction of sample A, and A CMD, results in the cross-machine direction of sample A. Results of tests in samples A, B, C, D, and F are presented.

The results of tensile strength are the averages of the five specimens tested in each direction (MD or CMD) for each sample. it can be seen that the ASTM D6693 presents higher rates of variation, in particular for fPP geomembranes. Figure 6 shows the results of elongation at break obtained in these tests.

Through the graphs shown in Figure 6, it can be seen that the ASTM D882 and ISO 527-3/NBR 15856 show similar results for the materials tested, but ASTM D6693 presents a reduction of approximately 40% over the previous ones. It may be noted that the fPP 0.60mm and fPP 0.90mm have much higher elongation compared to PVC. Moreover, such elongation is not a function of the thickness of the fPP geomembrane, since the values achieved for the samples are very close in this case. It can be seen that the ASTM D6693 presents higher rates of variation, in particular for fPP geomembranes.

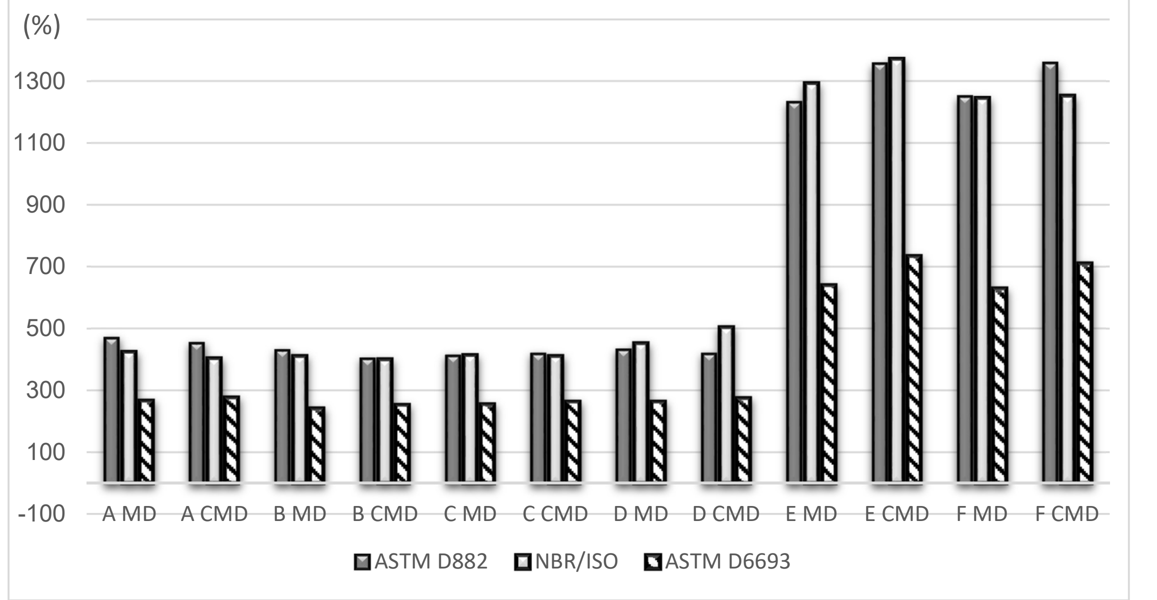


a) Mean values

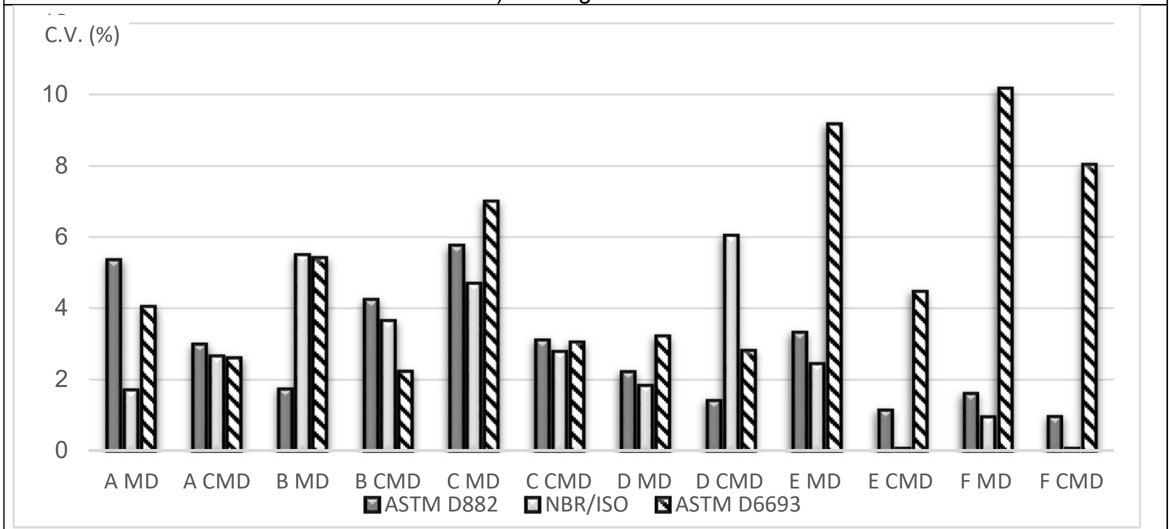


b) Coefficient of variation (%)

Figure 5. Results of tensile strength at break (average of 5 specimen).



a) Elongation at break



b) Coefficient of variation

Figure 6. Elongation at break observed in tensile strength tests.

4.2 Estimated error

Figure 7 presents the error estimated for the tests considering acceptable a normal distribution for the results. The overall average of the estimated errors considering all the parameters obtained by the same standard was 4% for ASTM D882 and ISO 527-3/NBR 15856, and 9% for ASTM D6693.

To reduce an 8% error to 5%, about 7 extra specimens need to be tested, while an error exceeding 18% indicates that an estimated number of more than 60 specimens is necessary to reduce it to 5%.

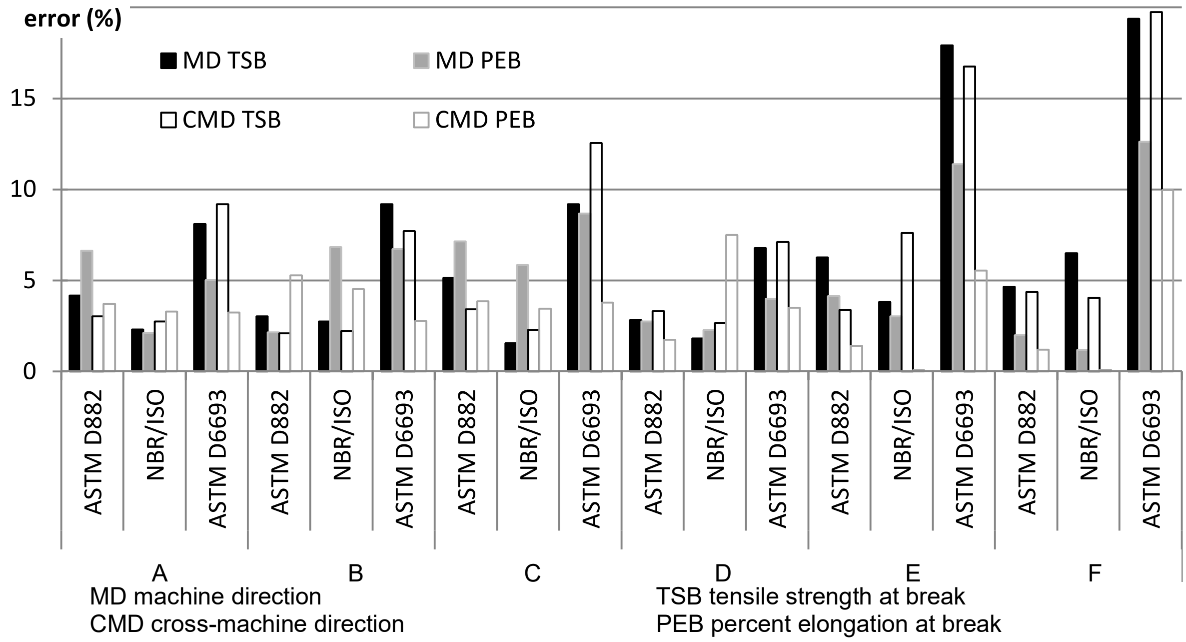


Figure 7. Estimated error for each test.

4.3 Comparative analysis considering ASTM D638

PVC-P samples with 1.0mm thickness in principle should be tested by ASTM D638 and not by D882. However, some recommendations also indicate the use of ASTM D882 in this case, as discussed in 2.2. To evaluate the effects of using either standard, tests following both procedures were performed for sample A.

Table 3 presents the results of comparative analysis for sample A, which also includes tests according to ASTM D6693, even if this standard is not indicated for PVC-P. The parameters obtained by ASTM D638 are quite different than those obtained by ASTM D882, being convenient the recommendation of ASTM D7176 performing D882 for tests even for thicknesses greater than 1.0 mm. This recommendation presents a special relevance when considering that ASTM D882 results are very close to ISO 527-3 results. Figure 3 allows observing a very similar behavior between specimens tested by ISO and ASTM D882, which is not observed in the specimens submitted to ASTM D638 or D6693.

Regarding the number of specimens, ASTM D882 and ISO 527-3/NBR 15856 results present both the lower variability and five specimens are sufficient to determine tensile strength.

Table 3 Comparative analysis for sample A.

Parameter	Standard	D638	D882	D6693	NBR/ISO
Tensile Strength at break	average (kN/m)	14.3	15.5	14.0	15.2
MD	σ (kN/m)	0.9	0.5	0.9	0,3
	error (%) for *N*=5	8	4	8	2
	Nmin for *e*=5%	13	3	13	1
Tensile Strength at break	average (kN/m)	11.0	13.7	12.3	12,8
CMD	σ (kN/m)	1.5	0.3	0.9	0.3
	error (%) for *N*=5	17	3	9	3
	Nmin for *e*=5%	56	2	17	2
Percent elongation at break	average (%)	294	471	267	423
MD	σ (%)	10	25	11	7
	error (%) for *N*=5	4	7	5	2
	Nmin for *e*=5%	3	9	5	1
Percent elongation at break	average (%)	290	454	277	402
CMD	σ (%)	11	14	7	11
	error (%) for *N*=5	5	4	3	3
	Nmin for *e*=5%	4	3	2	2

5 CONCLUSIONS

Projects involving polymeric membranes need frequent and reliable quality control and it is very important to define a standard test procedure that can cover favorable conditions to the particularities of each material.

The comparison between ASTM D638 (suitable for plastics with thickness greater than or equal 1.0mm) and D882 (suitable for plastic with thickness of less than 1.0mm) showed a significant difference for the tested sample and the ASTM 7176 recommendation to employ ASTM D882 to PVC-P geomembranes up to 1.5mm allows to have better results, closed with NBR/ISO ones. ASTM D638 results are closed to ASTM D6693 results, presenting the problems discussed in the next paragraphs.

In this study, it can be seen that the ISO 527-3 standard, technically identical to the ABNT NBR 15856, is the most suitable for unifying the test method for determining tensile properties of polymeric membranes due to its versatility and low dispersion of results, with an estimated average error of 4%.

ASTM D6693, despite a reasonable equivalence in terms of tensile strength at break, presents wide dispersion of results, with high estimated errors (9.5%), and a large difference in the percentage of elongation at break, with average values 40% lower than those obtained by NBR 15856 or ISO 527-3.

ASTM D882 is always preferable for all polymers if ISO 527-3 or NBR 15856 cannot be conducted. The results obtained by D882 were closed to the results obtained according to ISO, for tensile and elongation at break.

An analysis of the literature shows that frequently the authors that discuss tensile properties do not indicate the procedure adopted for testing. Considering the differences observed, it is essential to indicate always the test method employed.

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