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Hydraulic behavior of unsaturated nonwoven geotextiles under hydrostatic pressure tests

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ABSTRACT
Nonwoven geotextiles have been widely used in geotechnical and environmental engineering applications for separation, filtration, and drainage. However, the literature reports that geotextiles may exhibit resistance to water penetration at initial wetting. Despite the initial wettability deficiency tends to disappear once wetted, the wetting problems of the fabric could deeply disturb the drainage system operation, particularly in applications in which geotextiles may perform for a considerable time in an unsaturated condition and under wetting and drying cycles, like capillary barriers and thin cover layers. Nowadays, only EN 13562 requires the unsaturated behavior evaluation of a geotextile subjected to hydrostatic pressure. Nonwoven geotextiles specimens generally present a specific behavior with a different wet area, even if the test results do not have a great variation. This process is governed by many geotextile intrinsic characteristics beyond polymer, as geotextile structure and the manufacturing process. The scope of this paper is to discuss the behavior of nonwoven geotextiles in these tests, comparing the specimen wet area registered in hydrostatic pressure tests.

1. INTRODUCTION

The use of geotextiles as drain envelope material has been used systematically since the late seventies. However, the wettability deficiency of geotextiles has been posed in France in the early eighties through observing the standing water at the sports field surface as well as giving particular attention to the behavior of some drain pipes wrapped with a nonwoven geotextile (Lennoz-Gratin 1987, Dierickx 1996). Noticing a decrease in discharge of some of these drains a few months after installation, even after conspicuous rainfalls, laboratory tests have proceeded. However, it was noted in a preliminary visual inspection that the digged-up samples did not suffer mineral clogging deposits and kept the original characteristics of the product, inferring the problem of water resistance.

It is not surprising to find out that even woven geotextiles posse a resistance to water penetration. Indeed, the geotextile wettability deficiency is a product dependent problem and can be regarded as the fact that geotextiles are made predominantly of polypropylene and polyester whose hydrophobic and repelling properties are well known. According to Lennoz-Gratin (1987), the resistance to water penetration is not concerned only to the polymer but is due to the nature of the fibers and on the geotextile structure (pore size, thickness, ..) and the fabrication process (maybe the draw plates lubrification). However, the mentioned author also pointed out that only fine texture nonwoven geotextiles seem to be involved in wetting problems and the solution for this kind of fabric could be to treat the fleece of the geotextile with a wetting agent.

To ascertain whether geotextiles wettability is an initial or a permanent problem, Dierickx (1996) carried out laboratory experiments using both a sand tank model and a “wettability resistance apparatus”, that consisted of two concentric cylinders made of plexiglass. In the former the author carried out the experiments with both dry and moist envelopes as well as with dry and moist sand; in the later, it was used watercolored with a fluorescein solution. The investigations into the wettability resistance showed that initially dry geotextiles with initially dry sand result in a higher wetting resistance than the initial and dry and moist geotextiles combined with moist sand; the initially dry and moist geotextiles combined with moist sand posses about the same wetting resistance. The author also concluded that for most of the investigated geotextiles the variability in the wettability resistance is rather limited, regardless of the fact that some products exhibit a large variability. Finally, it was outlined that although mainly an initial problem, the resistance to water penetration of geotextiles can exert a negative effect where the soil structure is important.

However, it is important to outline that nonwoven geotextiles are primarily used in drainage applications over wet soils or they undergo hydraulic loads that lead to fast saturation. Nevertheless, in some particular applications, as capillary barriers and leak-detection systems, geotextiles may perform for a considerable time in an unsaturated condition. While the saturated hydraulic properties and saturated flow behavior of geosynthetics textiles are well understood and saturated properties are controlled and provided by manufacturers (e.g. EN 13252), the unsaturated hydraulic properties and unsaturated flow behavior of geotextiles are scarcely discussed on the literature. One particular point that deserves further study is the penetration processes of a water droplet into a pore.

Hence, this work discusses the results of water penetration resistance tests conducted in nonwoven geotextiles and presents some reflections about the influence of the geotextiles hydrophobic behavior. Additionally, this paper presents a study on the wet area left after the water penetration resistance test, which is little explored in the literature.

2. PERCENT OF WET AREA

In the first procedure proposed to determine the geotextile water penetration resistance, it was required the evaluation of the wet area. Lennoz-Gratin (1987) discussed the interest to understand how the water flows through the unsaturated geotextile and recommends to obtain the percentage of the wet area of the specimens subjected to the test. Fourteen fabrics were analyzed in this work, that measured hydraulic heads range from 0 to100 mm. From these 14 samples analyzed at least 8 presented hydrophilic behavior, with whole or almost whole of sample surface wet. However, some samples required hydraulic pressure to promote flow; in this case, it was observed that only 20% of the specimen surface was wet and the vast majority exhibited even lower values (lower than 10%). Based on these results, the referred author suggested that only the materials that display the hydraulic head smaller than 5 mm and the wet area equal to the total surface sample should be employed in drainage systems. It is important to stress out, however, that the hydrophilic behavior can be temporary, as it was pointed out by Vidal et al. (2014); in addition, it must be noted that the wettability deficiency of geotextiles ceases to be a problem for fully saturated ou in a highly moist medium.

Later, Dierickx (1996) tested 15 geotextile samples (10 nonwovens, 4 woven and 1 composed by woven and nonwoven) and only 2 of the nonwoven geotextiles presented resistance to water penetration. Table 1 resumes the observed results. Regarding the wet area, Dierickx (1996) reported difficulties with its definition and considered that the results are limited due to the high variability of measurements. Hence, Dierickx (1996) concluded that the wetted area measurements did not give additional information and are not relevant in design.

Table 1 Dierickx (1996) tests results

	Tg (mm)[3]	O_{90} (mm)[4]		h (mm)[5]	CV(%)[6]	%A[7]	CV(%)
NWNP[1]	3.2	0.167	FACE A	26	2.5	3.4	71.3
			FACE B	27	7.4	7.1	88.4
NWHB[2]	0.81	0.183	FACE A	37	22.4	not visible point flow	
			FACE B	45	48.8	not visible point flow	

[1] nonwoven needle-punched
[2] nonwoven heat bonded
[3] thickness
[4]characteristic opening size
[5] water penetration resistance
[6] coefficient of variation
[7] percent of wet area

Finally, it is important to outline that the standard published in 2000 (EN13562) no longer requires wet area determination.

3. MATERIAL AND METHOD

The experimental apparatus is based on the standard EN 13562 recommendations. The aspects related to the water penetration resistance test and the standard procedure are addressed in more detail by Avancini et al. (2020).

In this research, some modifications were made to the apparatus, which is presented in Figure 1. As a transparent cylinder with a circular area of (100 ± 1) cm^2 was not found, a plexiglass cylinder with an inner diameter of 14.5 cm was used, totaling a circular area of 165.1 cm^2. To guarantee that no deformation of the specimen could occur during the test, a wire screen was used.

The apparatus was adapted with cameras so that the maximum water level above the specimen and the time that the first drops of water began to pass through it, were recorded accurately. Two video cameras allow continuous recording of the water level above the specimen and its lower side. The water supply system was calibrated so that the rate of increase in water pressure when reaching the specimen was (100mm ± 5mm) / min as established in the standard,

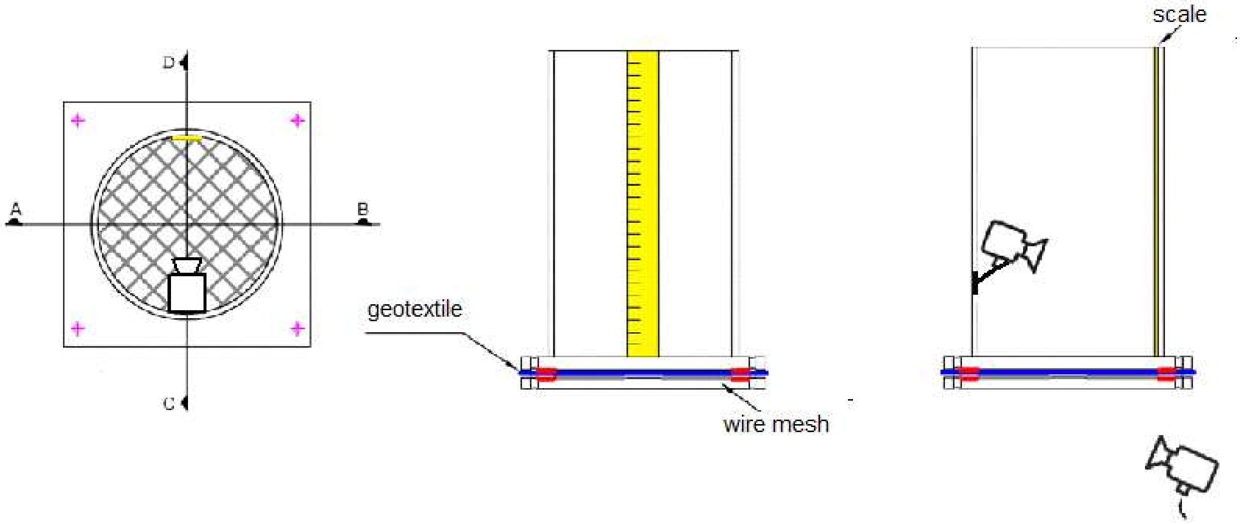


Figure 1 Schematic view fo the test apparatus.

The nonwoven geotextile employed in the tests is a nonwoven needle-punched of continuous filaments of polyester. Figure 2 presents a view of the product. The characteristics of this nonwoven geotextile are presented in Table 2. As provided in the standard, ten specimens were tested, five for each face of the geotextile. Thus, the nomenclature "Face A" was adopted for the inner side of the roll and "Face B" for the reverse side.

Figure 2 View of the geotextile

Table 2 Geotextile characteristics

characteristic	standard	unity	average value	CV (%)[3]
Nominal thickness[1]	ISO 9863-1	mm	2.5	5.4
Mass per unit area[1]	ISO 9864	g/m^2	257	5.4
Characteristic opening size[1]	ISO 12956	mm	88	
Apparent Opening Size[2]	ASTM D 4751	mm	0.18	
Permissivity[2]	ASTM D 4491	s^{-1}	1.3	

[1] sample results
[2] manufacturer characteristic values
[3] coefficient of variation (100 x standard deviation/average value)

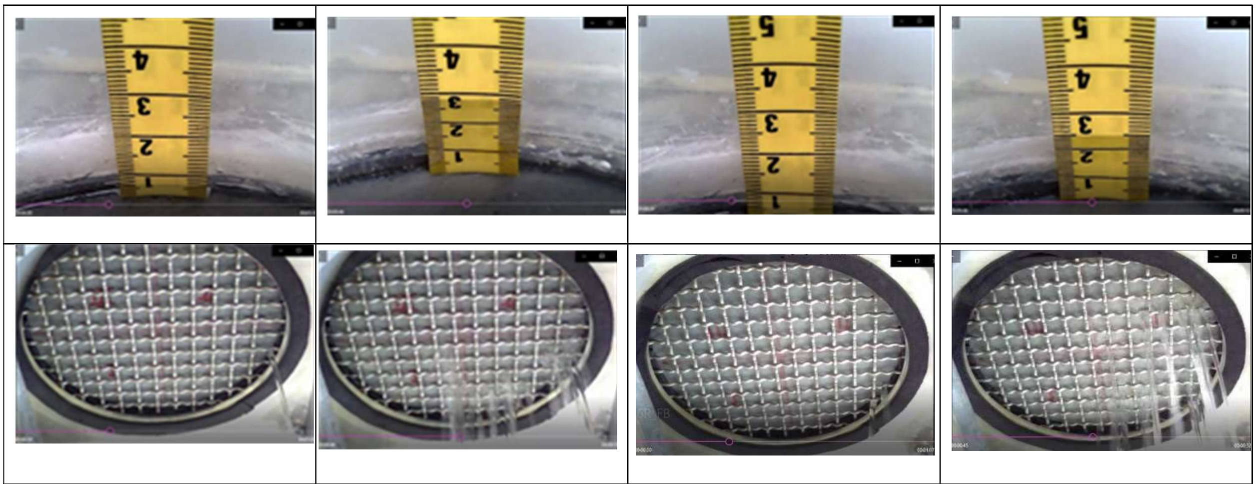
4. RESULTS AND DISCUSSION

4.1 The Water Penetration Resistance (WPR)

Table 3 present the maximum values of water height reached by geotextiles in tests of resistance to water penetration. Figure 3 shows some images obtained from the videos registered during the test to allow visualizing the water passage. The values found for maximum water height for the nonwoven geotextiles ranged from 28 to 34 mm for Face A (inner side of the roll) and from 25 to 30 mm for Face B.

Table 3. Results of the water penetration resistance test.

Face	Specimen	h max (mm)	WPR (mm)	CV (%)
A	F6R	28	30	8
	G6R	30		
	H6R	29		
	C1R	34		
	C8R	30		
B	F1R	30	26	8
	I4R	26		
	I6R	25		
	J7R	25		
	C7R	25		



00:00:30	00:00:46	00:00:30	00:00:46
Face A – H6R		Face B – I6R	

Figure 3. Passage of water through the specimens of the geotextile nonwoven

4.2 Wet Area

Immediately after the test, the specimen was pictured to evaluate the wet area. Both sides of the specimen were pictured. The images of the wet area obtained for “Face A” are shown in Figure 4 and for “Face B” are shown in Figure 5. The first column presents pictures of the side exposed to water and the second column presents the respective picture obtained in the side does not expose to water.

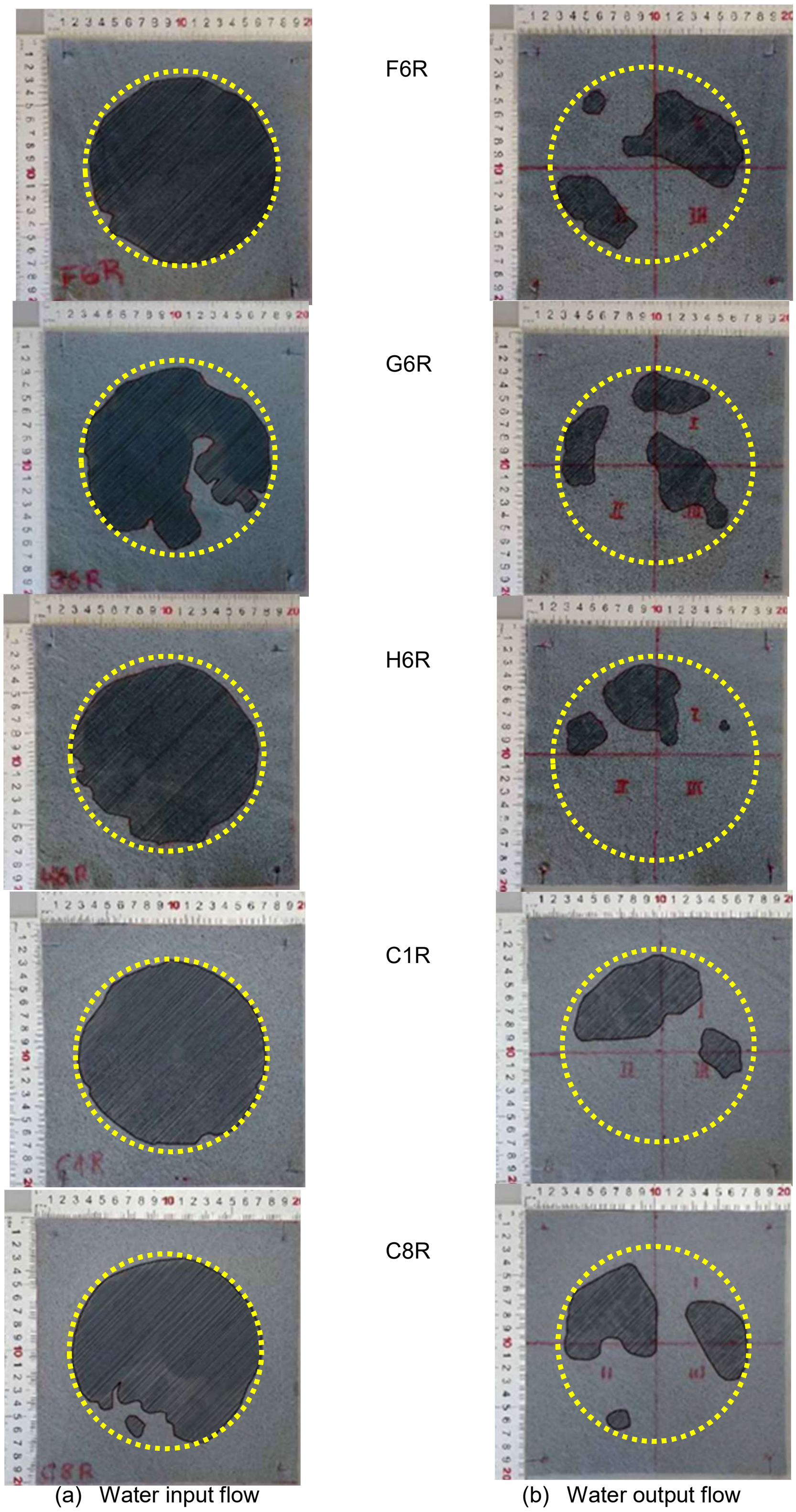


Figure 4. Images of the wet area of the specimens tested on Face A.

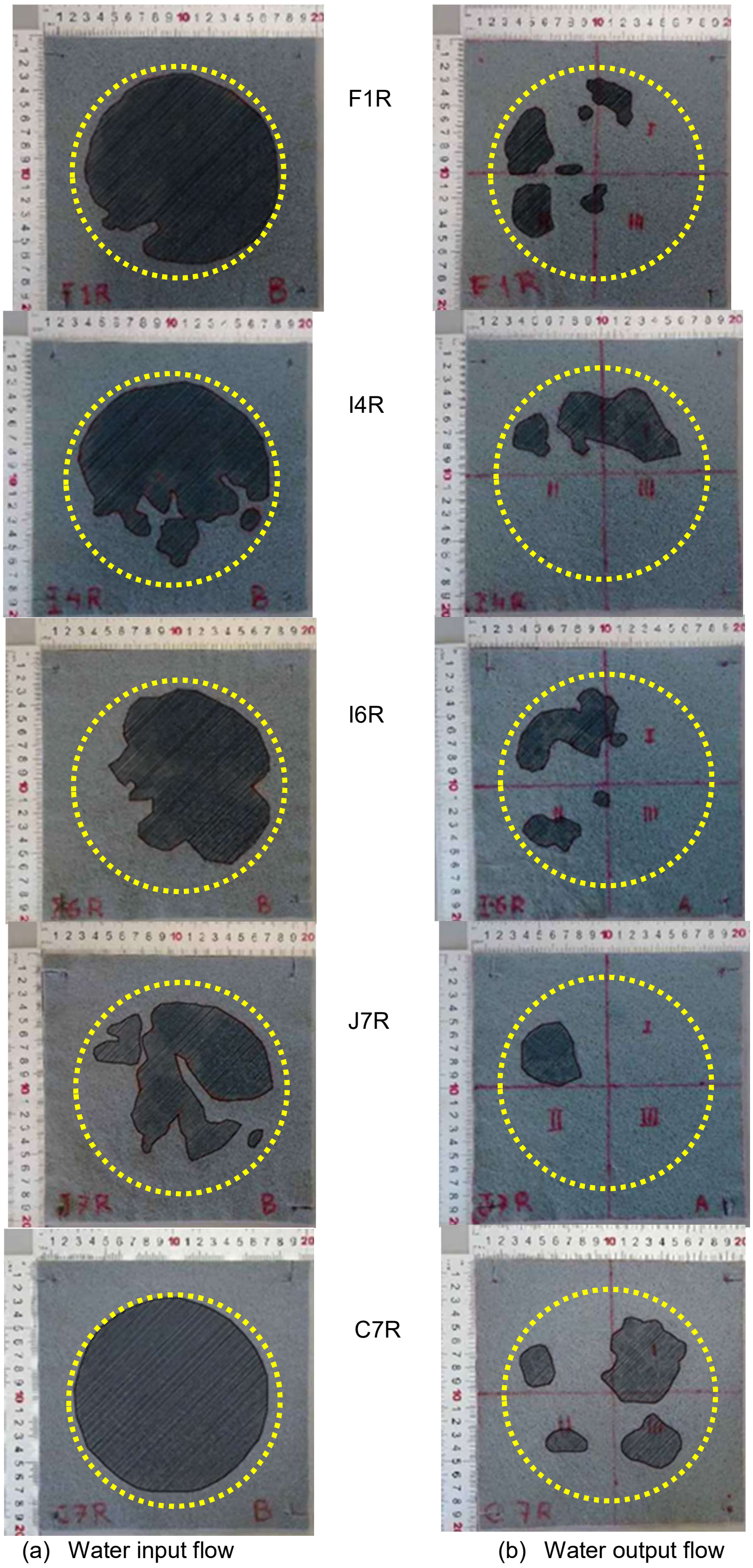


Figure 5. Images of the wetted area of the specimens tested on Face B.

Table 4 presents the wetted area values for the water input and output flow for all specimens tested. By the images is possible to see that the outflow of water provides a variable wetted zone between the specimens, however, the variation in the percentage of wet area for Face A was lower than that for Face B. The values of the coefficient of variability (CV) of the percentage of wet area for the water output on Face A was 20, while the CV on face B was 37.

Table 4.Wet area measurements

	Specimen	Area (%)		Average Percentage of area			
		Input	Output	Input	CV[1] (%)	Output	CV[1] (%)
Face A	H6R	87	21	89	6.3	31	19.9
	G6R	81	30				
	F6R	96	34				
	C8R	89	37				
	C1R	93	30				
Face B	F1R	91	21	75	24.7	21	36.8
	I4R	68	23				
	I6R	67	20				
	J7R	53	10				
	C7R	98	31				

[1]CV: Coefficient of Variation = Standard deviation / Average) x 100.

For comparison purposes, some tests were performed on Face A with a rate of pressure increase of 10mm/min. These tests indicated an average of 70% of wet area for input flow (CV = 8.3%) and an average of 10% for output flow (CV = 34.0%). These values are more appropriate for comparison with the results of Lennoz-Gratin (1987) and Dierickx (1996) because the tests conducted by these authors were done at a rate of 10 mm/min.

Comparing the results presented for the output flow (the bottom of the specimen), Lennoz-Gratin (1987) and Dierickx obtain wet areas similar to the area obtained in the tests with the same rate of hydrostatic pressure increase, but with greater variability (CV>70% in Table 1). In fact, Dierickx (1996) obtained values varying from 0.1% to 12% of the wet area in one face – 0.1% signifies an area of 0.1cm^2.

Comparing the results obtained with the different rates of pressure increase, if this rate increase, the wet area increases significantly.

5. CONCLUSION

Geotextiles are generally composed of hydrophobic materials and its wettability in an unsaturated condition can affect the hydraulic behavior of the water flow, leading the accumulation of standing water soil/geotextile interface. That behavior does not represent a geotechnical problem in most cases, due to the small hydrostatic pressure necessary to break the resistance to water penetration and because once this resistance is broken, the flow happens quickly restoring the system's permeability.

The influence of the resistance to water penetration is more relevant in superficial drainage systems, pavements, and thin cover layers, subjected to wetting and drying cycles. Due to some problems observed in drainage systems employed in agriculture, a simple test to measure the geotextile resistance to water penetration was proposed in 1988 and modified in 2000.

This resistance to water penetration leads some authors to discuss the interest of also evaluating the percentage of the wet area. Lennoz-Gratin (1987) does not recommend the use of geotextiles whose resistance to water penetration was greater than 5 mm or whose wet area was less than 100% of the tested area in all drainage systems.

In fact, even if several products present a water penetration resistance near to zero, that condition may not be permanent considering the test procedure does not recommend to previously wash the specimen. The major part of the products that present a very low resistance to water penetration is nonwoven geotextiles made with fibers that receive an additive during the manufacturing process, generally a lubricant oil, which gives a temporary hydrophilic condition to the product.

The passage of water in unsaturated nonwoven needle-punched geotextile occurs differently than in the unsaturated nonwoven heat bonded or woven geotextiles, being more frequently concentred in one or two parts of the specimen area, increasing the interest of to study this product.

The water penetration resistance (WPR) obtained in Face A (inner side of the roll) and the wet area after the passage of water through the specimen are different those obtained in Face B. Face A presented a water resistance 15% than that of Face B, but the wet area is 48% than that of Face B. It is also clear that the wet area in Face A is more continuous of the wet area in Face B, that presents up to 6 passage points.

The wet area of the outflow of water from the geotextile is 3 times smaller than the input flow, which may mean that after breaking the resistance to water penetration, there is a path through which the water passes that does not change until the end of the test.

The values of the wet area found in the tests with a rate of pressure increase of 100 mm/min are higher than the values found in the tests with a rate of 10 mm/min, indicating that the rate of pressure increase influence significantly the results of the test.

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