Model of Damage Accumulation Using Different Amplitudes of Loads for Geosynthetics

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Abstract— **The use of geotextiles in the role of reinforcement in roads or railroads increases the load capacity of the system due to a better stress distribution. In this case, it is taken into consideration among other features resistance to mechanical damage, rigidity and tensile strength. There are some mechanisms in geotextile damage, but they need more studies on this subject. The damage models have been accepted as alternative for the simulation of constituent behaviors of the materials that present loss of rigidity. This work considers a new methodology for damage in woven geotextile of polypropylene (PP). This proposal appeared after verifying that the theoretical and experimental studies do not consider the past history of the applied loads, or that for each load there is damage associated. Thus, the objective is to develop a model of damage accumulation in woven geotextile based in applied load.**

Index Terms — **Model, damage and geosynthetics.**

I. INTRODUCTION

Geosynthetics are polymeric materials with many applications in geotechnical and environmental works, mainly since the 1980s. These materials are used above or confined in soil, which may be in contact with differing agents that can trigger its degradation [1]. Heat, oxygen and climatic agents as ultraviolet radiation, humidity and rainfall are factors commonly considered in applications above the soil. For geosynthetics confined in soil, the particles size of soil and their angularity, acidity and alkalinity, temperature, presence of metal ions, oxygen, moisture, organic and microorganisms can be inclued [2].

Geotextiles have been used in various applications such as separation, filtration, reinforcement and protection [3]. To perform any of these functions, it is essential that the geotextile remains intact for a time and are not submitted to extreme loads, in some cases a level of damage is acceptable. The durability of geosynthetics is a complex theme, because it depends directly on the strength and compatibility of the polymer with site in which it is inserted as well as others project requirements [4].

Conceptually, the durability of geosynthetics can be understood as maintaining of their performance in contact with agents that lead to degradation of the polymer chain and consequent reduction of life-time [5]. As direct consequence of the degradation, occurs the aging of these materials, including changes in their physical, chemical and mechanical properties. Therefore, the durability of geosynthetics refers to their resistance to aging [5].

The pioneer work that introduced the damage concept was elaborated by Kachanov in 1958, initially in steel [6]. He tried to justify the rupture, precociously observed of materials, in slow deformation regimen, as consequence of the existence of defects in the material. For consideration of the damage, it was defined a variable to scale the material free of defects, D=0. While, D=1 corresponds a state of complete loss of integrity of the internal structure of material. D is given by Equation 1.

$$D = \frac{A_D}{A} \tag{1}$$

Where: A_D is the area with defects (cracks) and A is the total area (nominal) of the total area (nominal) of the transversal section, as presented in Figure 1.

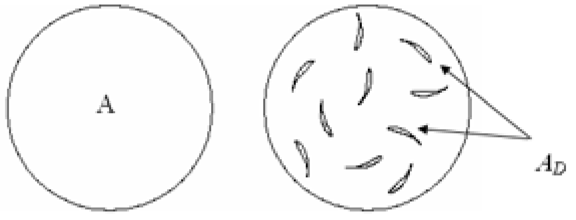

Fig. 1. Damage model.

Properties such as tensile strength, puncture resistance and unit weight have long been recognized as the key parameters. Some systems also consider the importance of both strength and elongation properties.

Time variant reliability assessment of deteriorating structures involves estimation of the damage due to random dynamic loads. In real life structures, the load effects causes damage [7]. Performed field trial on different nonwoven geotextile and concluded that the energy absorption of geotextile is an important parameter in the determination of damage resistance [8].

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The damage models have been accepted as alternative for the simulation of constituent behaviors of the materials that present loss of rigidity. Physically, the degradation of the mechanical properties of the material is the consequence of the increase of micron defects, between them, micron pores and micron cracks. These factors associated with applied cyclical tensions are favorable to the increase of the fatigue damage [9].

In general, a structure is designed to work with an appropriate level of safety and economy. The collapse of a structure can happen through two different mechanisms [10]:

- The occurrence of high load levels that exceed the resistance capacity of the material, causing failures, for example, rupture or instability of a structural component;
- The structural collapse caused by accumulated damage produced by repetitive action of variable loads even for lower tension levels generating a fatigue process.

The accumulating processes of damage can produce imperfections in the material due to the cyclical carried generating fatigue [11]. The evolution of the damage can be linear or non linear, as presented in Figure 2.

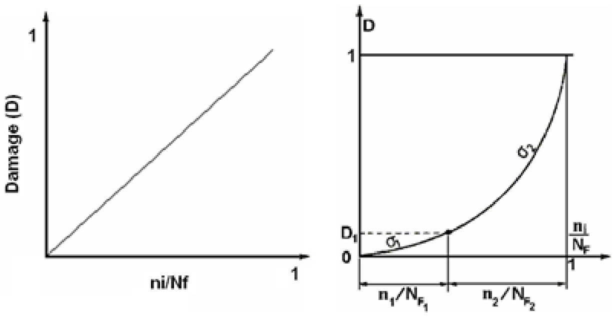

Fig. 2. Linear and non linear model damage

Where: n_1 and n_2 are numbers of cycles, N_{f1} and N_{f2} are numbers of cycles to rupture in relation the stress [σ].

II. MATERIALS AND METHODS

In this work, to study the accumulation of damage in a geotextile, specimens of the material were submitted to chosen deformation patterns. Their strength was later determined using tensile tests using the strip method described in ASTM D 5035 [12]. Evaluating the accumulated damage induced a model that was implemented.

The results of the accumulated damage obtained with the model are presented. Table 1 shows some of its properties.

TABLE I
PROPERTIES OF GEOTEXTILE EMPLOYED IN THIS STUDY.

Properties	Value
Polymer type	PP
Mass per unit area (NBR 12568 2003) [13]	459.6 g.m-2
Ultimate Tensile strength (ASTM D5035 2011)	105.4 kN.m-1

The size of the samples was 50mm versus 75mm, dimensions compatible with the mechanical characterization of Strip Method.

For each load applied correspond certain damage and this may leads to the rupture of the geotextile. Tests to induce accumulated damage were carried out following the loads shown in Figure 3.

These loads consist of 11 cycles. The values of the applied loads are varied. The last applied load causes the geosynthetic rupture.

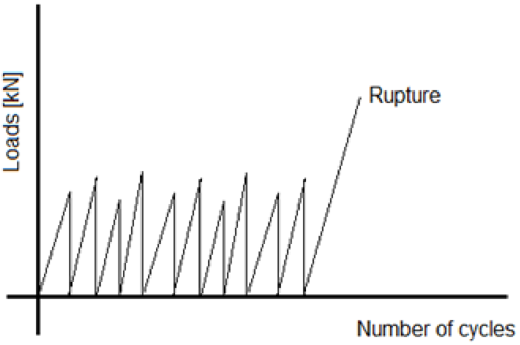

Fig. 3. Schematic used in tests of samples

The tensile strength of the geotextile was on average 5.25 kN. Tests were performed with two series. The first was an average of 30 to 38% of the tensile strength. The second was an average of 40 to 50% of the tensile strength.

Table 2 includes the designations given to the loads imposed, during the tests and the corresponding accumulated damage induced.

TABLE II
DAMAGE OBTAINED IN THE APPLIED LOADS

Series	1		2	
	Loads (F)	Damage (D)		
0	F0		F0	
1	F1	D1	F1	D1
2	F2	D2	F2	D2
3	F3	D3	F3	D3
4	F4	D4	F4	D4
5	F5	D5	F5	D5
6	F6	D6	F6	D6
7	F7	D7	F7	D7
8	F8	D8	F8	D8
9	F9	D9	F9	D9
10	F10	D10	F10	D10
11	F11	D11	F11	D11

A. Proposal of Methodology for calculation of the accumulated Damage in geotextile

The proposal of this methodology presents that the total damage is determined by the addition of partial damages *Di* of each parcel. Each parcel of the *Di* damage is determined by the relation of the initial load (F_1) is divided by the maximum load of the material (F_0). From the second parcel, the load (F_2) is by the divided maximum load of the material (F_0) and is multiplied by exponent of the Damage (D_1) accumulated divided (F_2) and thus successively, in accordance with the Equation 2 and 3.

$$D = D_1 + D_2 + D_3 + D_4 + \ldots + D_N \qquad (2)$$

$$\frac{F_1}{F_0} + \frac{F_2}{F_0}\exp(\frac{D_1}{F_2}) + \frac{F_3}{F_0}\exp(\frac{D_2}{F_3}) + + \frac{F_4}{F_0}\exp(\frac{D_3}{F_4}) + \ldots + \frac{F_n}{F_0}\exp(\frac{D_{n-1}}{F_n}) \qquad (3)$$

Where: D = total damage, D_1 = damage accumulated 1, D_n = n damage accumulated, F_0 = maximum load obtained by tensile test; F_1 = first load applied; F_2 = second load applied; F_3 = third load applied.

III. RESULTS

The results presented in Figure 4 refer to the tensile tests (10 specimens) and include the average tensile strength and corresponding deformation.

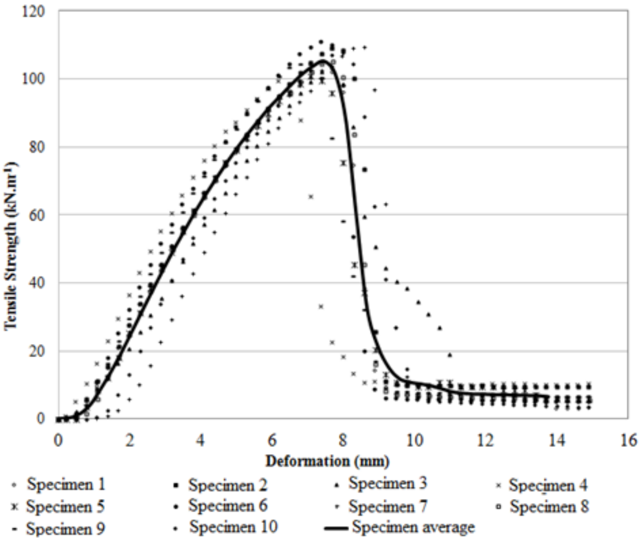

Fig. 4. Tensile Strength versus deformation

From the data obtained the tensile strength of material was determined (105 kN/m) and the corresponding maximum deformation was 7.337 mm.

The results obtained with the loads applied in series 1 were:

TABLE III
DAMAGE OBTAINED WITH APPLICATION OF THE LOADS.

Serie	1					
	Sample 1		Sample 2		Sample 3	
	F [kN]	D	F [kN]	D	F [kN]	D
0	5,2500		5,2500		5,2500	
1	2.3760	0.4526	2.1890	0.4170	2.1550	0.4105
2	2.4440	0.5602	2.0590	0.4802	1.9960	0.4670
3	2.3330	0.5650	1.9980	0.4840	1.9750	0.4765
4	2.2620	0.5531	1.9740	0.4805	1.9190	0.4686
5	2.2300	0.5443	1.9320	0.4719	1.9000	0.4631
6	2.1790	0.5328	1.9250	0.4685	1.8790	0.4579
7	2.1560	0.5258	1.9040	0.4638	1.8540	0.4521
8	2.1240	0.5182	1.8960	0.4612	1.8490	0.4497
9	2.1080	0.5134	1.8780	0.4573	1.8400	0.4475
10	2.1040	0.5115	1.8760	0.4560	1.8180	0.4429
11	5.4430	1.1389	5.5450	1.1467	5.1520	1.0694

The results obtained with the loads applied in series 2 were:

TABLE IV
DAMAGE OBTAINED WITH APPLICATION OF THE LOADS.

Serie	2					
	Sample 1		Sample 2		Sample 3	
	F [kN]	D	F [kN]	D	F [kN]	D
0	5.2500		5.2500		5.2500	
1	2.9230	0.5568	3.3070	0.6299	3.7310	0.7107
2	2.6040	0.6142	3.0230	0.7092	3.2950	0.7787
3	2.5510	0.6182	2.8980	0.7051	3.2150	0.7802
4	2.4830	0.6067	2.8580	0.6967	3.1320	0.7653
5	2.4430	0.5965	2.8150	0.6868	3.0960	0.7551
6	2.4340	0.5924	2.7920	0.6801	3.0550	0.7451
7	2.4170	0.5882	2.7760	0.6756	3.0340	0.7388
8	2.3990	0.5839	2.7610	0.6717	3.0050	0.7319
9	2.3820	0.5798	2.7350	0.6660	2.9940	0.7282
10	2.3510	0.5730	2.7950	0.6756	3.0290	0.7338
11	4.6560	1.0030	5.0360	1.0970	5.1380	1.1289

From the results presented in Tables 3 and 4 it is possible to verify that the higher the applied load, the greater the accumulation of damage determined from Equation 2. Table 5 summarizes the main results obtained.

TABLE II
SUMMARY AND COMPARISON OF THE MAIN RESULTS OBTAINED.

Serie	Load [kN]	Damage
1	5.4430	1.1389
1	5.5450	1.1467
1	5.1520	1.0694
Average	5.3800	1.1184
St. Deviation	0.2039	0.0425
2	4.6560	1.0030
2	5.0360	1.0970
2	5.1380	1.1289
Average	4.9433	1.0763
St. Deviation	0.2540	0.0654

IV. DISCUSSION AND CONCLUSION

The incremental damage due to a loading is proportional to the amplitude of a load and the total damage is estimated by assuming a suitable damage accumulation rule.

Experiments demonstrate that the model developed for the accumulation of damage in geotextile woven is applicable because all values were equal to 1 or greater.

In relation the last load applied, note that in the serie 1, specimen failed with lower load compared to series 2. This may be associated with the damage accumulated in the geotextile, as in the first set the applied load was increased during the cycle.

The model can be accepted as an alternative to simulation of damage accumulation in geotextile.

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