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Influence of Biodestructors on the Wear Resistance of Polyester Geotextile Materials

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Received: 28 December 2018; Accepted: 29 January 2019; Published: 31 January 2019

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Abstract: Changes in the structure and properties of geotextile nonwoven materials after microbiological load under natural conditions have been studied. Microbiological research of samples was conducted after testing for 12 and 24 months. The results of the research of physical and mechanical materials properties prove their sufficient resistance to the influence of biodestructors.

Keywords: biodestructor; wear resistance; polyester; geotextile material

1. Introduction

Geotextile materials are mostly used in road construction, though they are also often applied in landscape architecture design. Geotextiles are used inside various earthwork structures (terraces), slopes, declivities, rockeries, alpine slides, ornamental water reservoirs, drainage systems, etc. These materials prevent the mixing of different material layers, strengthen loose ground, protect hydraulic systems from physical and mechanical destructions, and restrain the growth of plants roots and weed germination. Inside the soil, geotextiles are affected by dampness, temperature changes, soil pH, and the vital activities of microorganisms and animals, and they resist the pressure of layers with different fraction sizes.

Use of polyester fibers allows for geotextile materials with certain wear resistance properties. Fibers are specified by the enhanced mechanical properties, though they can be sensitive to hydrolysis. Therefore, fibers like these are necessary to determine the soil pH. Taking into account that soil is a salutary medium for microorganisms growth and their vital activities, it is reasonable to study geotextile resistance to biodestructor activity.

Polypropylene fibers are also used to produce geotextile nonwoven materials. The materials made of polypropylene fibers are strong, lightweight, and resistant to chemical reagent influence and microorganisms and to high and low temperatures (freeze-proof), with a high coefficient of friction, little tendency to peeling, low thermal conductivity, and an ability to drain moisture quickly.

Being in soil, the properties of geotextile nonwoven materials mostly change as a result of the action of the following factors: pH, the grain-size composition of the soil, temperature, moisture content, and the presence of oxygen and microorganisms [1–6]. Chemical destruction (disruption of polymers chains, sewing together, swelling or dissolution, a loss of ingredients of polymeric connection, an increase in the degree of crystallinity) depends on the type of polymer and the soil acidity or alkalinity. The alkaline hydrolysis of polyester fibers occurs if the value of pH exceeds 10, so the period of material exploitation made of this raw material should be limited. The internal hydrolysis under normal conditions occurs at all pH values based on the cross-sectional view of fibers.

The process can be slowed down during the use of polyester fibers with high molecular mass, a limited branching of chains, and an absence of acids in the soil.

The aim of the article is to conduct testing of geotextile nonwoven materials in the natural environment to define the influence of biodestructors on their wearability.

2. Materials and Methods

Conducting testing under natural conditions, linens of the geotextile nonwoven materials were dug in active soil for 12 and 24 months. During the period of the tests, under natural conditions, the geotextile nonwoven materials performed functions of division, filtration, and drainage and yielded to the influence of pressure, temperature, moisture, soil, etc., so a worsening of indicator values was observed. The soil used for the study was bleached with black soil, and the content of humus was up to 1.6–4.0% [7]. Humus, as a component of the soil, was found to be the most favorable environment for vital functions of various types of microorganisms. The microflora of the soil consists of numerous types of bacteria: putrid, nitrifying, nitrogen-fixing that decompose fibers, sulfur bacteria, etc. There can be aerobes and anaerobes among them, sporogenous and non-sporogenous. There are various fungi and algae. The simplest viruses are in the soil. There is a huge amount of microorganisms in soil: from hundreds of millions to milliards per gram of soil. The composition and amount of microflora of the soil depend on its humidity, temperature, acidity, composition, and the amount of nutritious substances in it.

After the expiration of these periods of being loaded, the samples under study were analyzed visually (both before and after cleaning). Visible changes in the structure of these fabrics were found. Signs of damage and separate fibers were recorded during microscopic investigation. Microbiological research was carried out too.

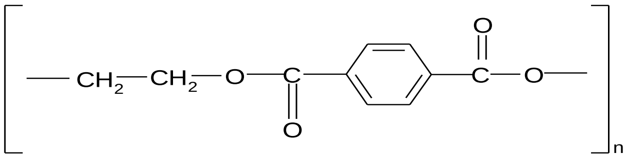
Testing of geotextile nonwoven materials was conducted in laboratory conditions using standard (State Standards of Ukraine 8607:2015 “Road Construction Geosynthetic Materials. Methods of Testing”) and adapted methods. During microbiological examination of a dense nourishing medium (meat infusion agar and wort agar), wipe sampling was made by the superficial method, and microorganisms were grown in a thermostat for 48 h (36 ± 1 °C). Bacteria, fungi, and yeasts were counted.

The results of the research were compared to the properties of the samples that did not yield to microbiological loading. Main specifications of the samples before the natural environment testing are shown in Table 1.

Table 1. Value of geotextile nonwoven materials indicators.

Sample Number	Fiber Type, Raw Material Components	Method of Production and Processing	Surface Density, g m^{-2}	Thickness, mm
1	100% polyester fibers	needled, thermoset, calendered	125.0	0.78
2	100% polyester fibers	needled, thermoset, calendered	200.0	1.06
3	100% polyester fibers	needled, thermoset, calendered, soaked	194.0	1.14

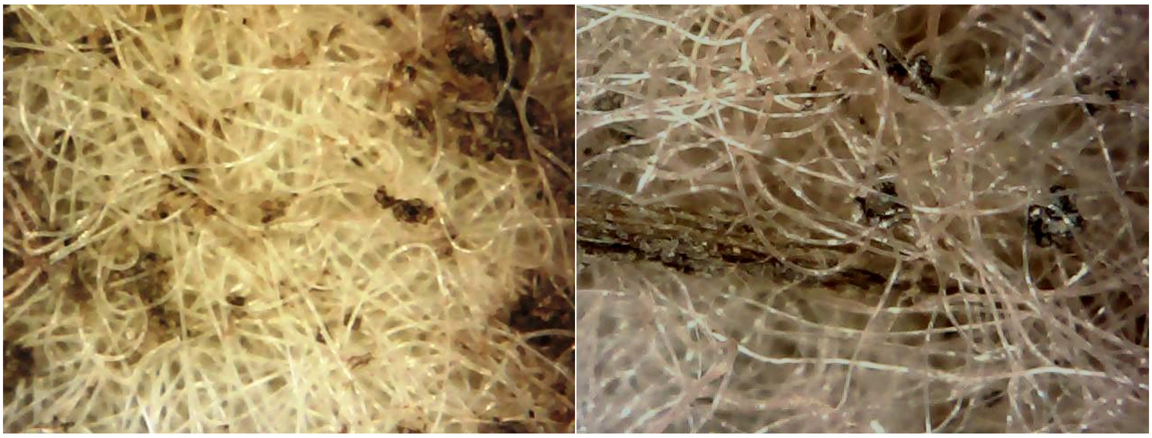
The examined nonwoven geotextile materials were made of polyester fibers—a product of terephthalic acid and ethylene glycol polycondensation. Monomeric link can be shown with the formula



Laying of the examined fabrics was formed on combing machines. Mechanical connection between fibers was created by way of needling from pulling fibers by the barbed needles through the entire thickness of the fabric with different densities of punctures per 1 cm^2. To provide an adhesion connection of fibers, the fabric was processed on calender machines with a temperature of 220 °C for 12–16 s. Thermofixation of fabrics implies treatment with hot air (230 °C) for 16–18 s. The third sample was soaked with styrene-co-acrylonitrile latex.

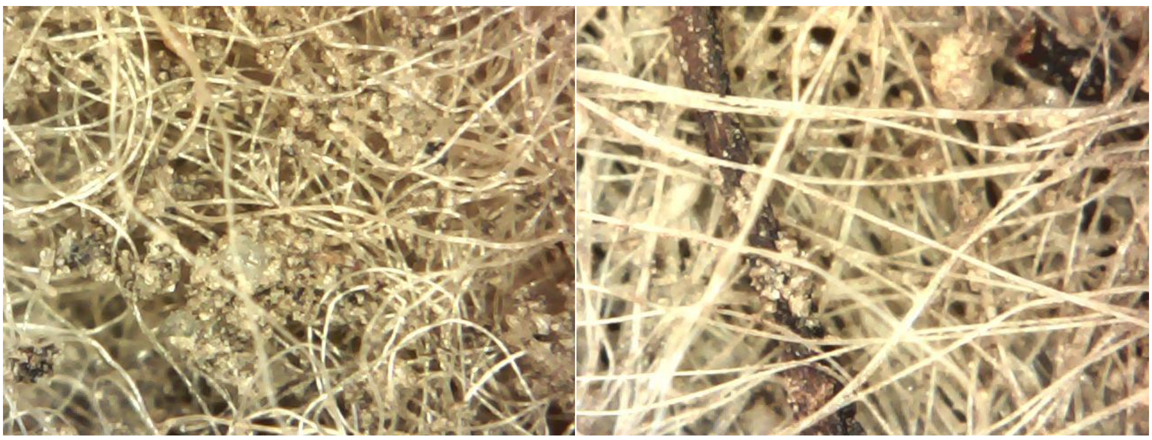
3. Results and Discussion

Damage of fabric integrity by plants roots was observed after 12 and 24 months of load on the materials. (Figures 1 and 2).



(**a**) (**b**)

Figure 1. Geotextile materials after 12 months of testing under natural conditions: (**a**) colmatage after testing; (**b**) penetration of plant roots after testing.



(**a**) (**b**)

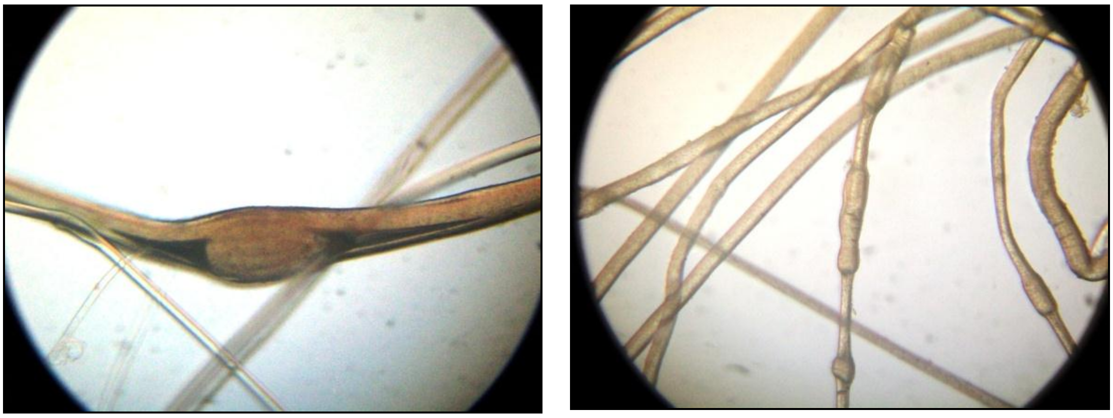
Figure 2. Geotextile materials after 24 months of testing under natural conditions: (**a**) colmatage after testing; (**b**) penetration of plant roots after testing.

After 12 months, colmatage was observed, but its place was local, mostly on the surface. Due to the fixed structure of the unsaturated geotextile thermoset nonwoven materials, the particles of the soil moved deeper into the layer of the fabric.

Colmatation after 24 months of testing was considerable with thorough penetration for all samples under research. For unsaturated geotextile nonwoven materials, the filling of pores by soil particles was characteristic, unlike for the geotextile nonwoven materials that were treated the same way (unless they were saturated).

Damage due to the germination of plants roots was observed both underneath and on the surface. Germination with a formation of the cross hole was recorded after both periods of testing. The size of the damage depends on the diameter of the roots, and the types of plants. Though the growing of roots in the layer of the geotextile nonwoven fabrics influences the physical and mechanical properties of geotextiles, it can also be considered a factor that additionally makes the structure of the fabric more compact, forming a framework.

Microscopic investigation of the samples under testing was conducted after visual inspection. During this investigation, the traces of destruction were found after digging into the polyester fibers: a thickening of the separate areas of the fibers, a cracking in the most swelled areas, and an occurrence of longitudinal cracks of different lengths (Figure 3).



(**a**) (**b**)

Figure 3. Image of the polyester fibers damages after digging (increase 200×): (**a**) local thickening with cavities; (**b**) swelling.

Damage found in the polyester fibers was characterized by a thickening of the separate areas, related to the local fixing of microorganisms due to adhesion and the following adsorption by the nourishing environment of the fiber. Cavities were visible in the places of thickening. Some thickenings, as a result of swelling, look like the inflated areas (swelling). The most widespread change in the macrostructure of the polyester fibers was observed as a local bulge as a result of swelling.

These changes in the polyester fiber macrostructure can be the result of microorganism generation in certain areas. Nutritious media for the active spread of microdestructors include dyes and saturating composites, which cause surface damage that is partly loosened by microorganisms.

In unsaturated geotextile nonwoven fabrics that had been in soil for 12 months, the number of mesophilic aerobic and optionally anaerobic microorganisms increased to $1.2 \cdot 10^6$ colony forming units per 1 g. Over 24 months, they increased to 7.8×10^6 and to 7.9×10^8 colony forming units per 1 g for materials saturated by acrylic polymer binders. In total, after testing in the natural environment, the share of microbiological destruction by bacteria was 99.9%, and that by fungi and yeasts was only 0.1% (Table 2). To minimize the microbiological destruction of geotextile materials, they can be combined with a thin layer based on zeolite composites. It is known that zeolite composites with silver are efficient antimicrobial agents [8–10]. Natural zeolites, being aluminosilicates, are compatible with soils of various types. The application of Ag^+-zeolite samples prevents leakage of Ag^+ toxic ions into soils or waters of soils, because the desorption of silver in such conditions does not take place in practice [8]. Ukraine has great deposits of natural clinoptilolite. In particular, the clinoptilolite deposit in Sokyrnytsia of Ukrainian Transcarpathia accounts for over 900 million tons.

Table 2. Degree of microbiological contamination of the geotextile nonwoven materials.

Type of the Sample	Bacteria, Colony Forming Units per 1 g		Fungi, Colony Forming Units per 1 g		Yeasts, Colony Forming Units per 1 g	
	Control	After Digging	Control	After Digging	Control	After Digging
			after 12 months in the soil			
1	3.8×10^3	1.2×10^6	1.1×10^2	3.4×10^3	1.3×10^2	2.9×10^2
			after 24 months in the soil			
2	5.3×10^3	7.8×10^6	1.4×10^2	5.9×10^3	1.2×10^2	3.3×10^3
3	6.4×10^3	7.9×10^8	1.8×10^2	7.1×10^3	1.5×10^2	7.6×10^3

As a result of the tests under natural conditions, physical and mechanical indicators of the geotextile nonwoven materials undergo changes. This research allows for an estimation of operating properties in the objects of landscape building and forecast life duration. Detected tracks of microbiological destruction do not considerably influence the value of physical and mechanical properties of the materials. Research on structural indicators, such as surface density, thickness, spatial density, and porosity preceded the determination of resistance and air permeability values (Table 3).

Table 3. Value of geotextile nonwoven materials indicators after digging.

Type of the Sample	Surface Density, $g\ m^{-2}$	Thickness, mm	Spatial Density, $g\ m^{-3}$	Porosity, %	Air Permeability, $dm^3\ (m^2 s)^{-1}$
		after 12 months in the soil			
1	138.8	0.88	0.16	88.57	835
		after 24 months in the soil			
2	277.8	1.34	0.21	84.98	346
3	373.1	1.38	0.27	80.41	117

Surface density increases due to the accumulation of soil particles in the fabric pores. The thickness of unsaturated geotextile nonwoven materials increased, which is explained by holes being filled up due to colmatation with the fixing of the fiber position of the fabric during processing. After 24 months of testing in the natural environment, there is also an increase in surface density and thickness due to considerable colmatation. The air permeability during both periods continues to go down, but the geotextile nonwoven fabrics do not lose permeability. Taking into account the changes in values after tests, it is possible to conclude that thermoset, calendered samples remain the most stable due to their structural characteristics, though reduction of air permeability is observed.

The process of colmatation of the geotextile nonwoven materials also influences their porosity, which, in turn, depends on the nature, the way of location, the fixing of fibers, the thickness, the surface density, and the fabric processing. Therefore, the porosity of the geotextile nonwoven materials without processing is characterized by the highest value of 93.6%; for the thermoset, calendered ones, it is 86.9% on average.

One more indicator that characterizes microbiological permanence and wear resistance is the loss of durability for a certain period of microbiological loading (Table 4).

Table 4. A change of durability values of geotextile nonwoven materials.

Type of the Sample	Before Digging				After Digging			
	Maximum Durability, kN m^{-1}		Relative Elongation at the Moment of Disruption, %		Maximum Durability, kN m^{-1}		Relative Elongation at the Moment of Disruption, %	
	By Length	By Width	By Length	By Width	By Length	By Width	By Length	By Width
after 12 months in the soil								
1	6.12	4.66	49	88	6.30	5.60	45	71
after 24 months in the soil								
2	7.87	8.16	54	80	7.17	9.87	45	65
3	11.40	8.95	42	68	10.60	7.31	39	44

The increase in the boundary value of durability by 3% by length and by 20% by width was observed after 12 months. After 24 months, the boundary value of durability of the geotextile nonwoven materials was reduced by 8% by length, but there was a growth in the value by width due to the increase in the surface density and thickness as a result of considerable colmatation with soil particles. Saturated geotextile nonwoven materials are characterized by the reduction in the boundary durability by 18% by width. The value of relative elongation at the moment of disruption also decreased after 12 and 24 months of testing in the natural environment.

4. Conclusions

As a result of microbiological researches, it was found that, after digging the samples under study in the soil, bacteria prevailed in washings up to 99.9% and that the amount of colonies of fungi and yeasts was just 0.1%. The growth of microbiological contamination was observed on all types of samples notwithstanding the raw material composition. The fibers of polyester had characteristic biodamages (local thickening and swelling as a result of swelling, cavities, and cracks of different sizes). A complete destruction of fibers was not detected.

After tests in the natural environment, the samples under study were characterized by an increase in surface density and thickness and a reduction in porosity and air permeability because of colmatation. The changes in these values depend on the initial structure of the geotextile nonwoven fabrics, the processing and properties of the soil, and the construction of building objects.

It was found that most changes in the samples under study occurred during the first year of application, after which there was a gradual decline in maximum durability and relative elongation at the moment of disruption that specified the availability of destructive processes.

Author Contributions: Conceptualization—O.V.K.; investigation, writing original draft—L.V.P.; data curation, writing, review & editing—V.O.V.

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflicts of Interest: The authors declare no conflict of interest.

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