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Biodegradable geotextiles – The use of biopolymers in short-lived soil protections

Géotextiles biodégradables – L'utilisation de biopolymères pour des applications courte durée de protection contre l'érosion

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ABSTRACT: Short-lived geotextiles find application in soil erosion protections and can improve seeding conditions on exposed surfaces. They usually are produced in the form of fibrous mats, which are fabricated from natural fibers or thermoplastic biopolyesters. In this work four different biopolyester were used for producing biodegradable fibers by a melt spinning process, which were then characterized by tensile testing. The fibers were exposed to artificial weathering in order to investigate the influence of moisture and UV-light radiation on the mechanical stability. The results were compared to non-stabilized polypropylene fibers, which are conventionally applied in synthetic geotextiles. Most biopolyester showed promising results regarding fracture strength even after 750 h of exposure. However the elongation at fracture was drastically reduced indicating embrittlement of the fibers.

RÉSUMÉ: Les géotextiles à courte durée de vie trouvent leur application dans les protections contre l'érosion du sol et peuvent améliorer les conditions d'ensemencement sur les surfaces exposées. Ils sont généralement produits sous forme de nattes fibreuses, elles-mêmes fabriquées à partir de fibres naturelles ou de bio polyesters thermoplastiques. Pour cette contribution, quatre bio polyesters différents ont été utilisés pour produire des fibres biodégradables par un procédé de filage en fusion. Ces fibres ont ensuite été caractérisés par des essais de traction. De plus les fibres ont été exposées à des intempéries artificielles afin d'étudier l'influence de l'humidité et du rayonnement UV sur la stabilité mécanique. Les résultats ont été comparés à des fibres de polypropylène non stabilisées, qui sont traditionnellement utilisées pour les géotextiles synthétiques. La plupart des bio polyesters ont montré des résultats prometteurs en ce qui concerne la résistance à la rupture même après 750 h d'exposition. Cependant, l'allongement jusqu'à la rupture a été considérablement réduit, ce qui indique une fragilisation des fibres.

Keywords: Biodegradable geotextiles; Short-lived geotextiles; Soil erosion protections; Polylactic acid; Biopolyester

1 INTRODUCTION

For several geotechnical applications, a controlled degradation of the geotextile material is desired. An example is the protection of newly seeded areas and slopes against soil erosion, where the rootless seeds can easily be washed out by strong rain and wind. In many cases, a well-developed natural vegetation is an efficient protection agains soil erosion, however it takes some time until it is fully established. Plant growth can be notably enhanced by applying geotextile mats on the exposed surface, where the seeds get entangled in the critical growing phase. When the geotextile is emplaced on slopes the velocity and amount of runoff is significantly reduced resulting in less soil erosion and improved germination conditions (Álvarez-Mozos et al., 2014; Bhattacharyya et al., 2010; Egbujuo et al., 2018). After a natural green cover has established, the exposed surface is protected from further erosion by the rooted plants and the geotextile becomes redundant. The geotextile is then either recollected manually, or left on the ground, which are both non-ideal solutions. Recollection can be a tedious task, as the plants are very often grown tangly with the geotextile and the mats cannot be removed without causing damage to the vegetation surface. In Figure 1 two types of geotechnical systems are shown, where plant growth has already started. In the first picture a dense and fibrous mat was used, which is difficult to separate from the plants even at a relatively early growing stage. Also the second photograph shows a case, where the removal of the geotechnical system would cause some damage to the newly formed vegetation.

Leaving the geotextiles on the ground is not preferential, because they could hamper further plant growth in some cases. When polymer based geotextiles are applied, the agglomeration of micro plastic and plastic additives has to be considered as another negative aspect. For the described applications, mostly non-degradable polymers such as polypropylene or polyesters are used, which are known to break down by UV-light exposure or hydrolysis. As these fragments cannot degrade in a biological way, micro plastic is accumulated in the ground. The UV-degradation of polypropylene can be hindered by adding adequate stabilizers, however these stabilizers and also other polymer additives tend to leach out of the polymer and accumulate in the soil as well (Wiewel and Lamoree, 2016).

Figure 1. Examples of revegetation, assisted by two different types of geotechnical systems

By using bio-degradable materials for such geotextile applications, negative impacts on the environment can be prevented. For some applications, bio-degradable geotextiles made of natural fibers, such as coir and jute, have been used (Gupta, 1991; Methacanon et al., 2010). Depending on the fiber's lignin and cellulose content, they show different degradations rates and levels of water uptake. Fibers, which have high cellulose contents show initial high strength but also high water uptake (Ghosh, M., Choudhury P.K. and Sanyal, 2009). This can lead to adhesion problems on slopes when the geotextile mat gets too heavy. Furthermore, constantly water-soaked mats can cause fouling of the seeds, which are spread under the geotextile.

Another option for these kind of applications are thermoplastic bio-degradable polymers, such as biopolyesters, which show varying rates of degradation, only moderate water uptake and can be degraded by microorganisms into environmentally safe components. Drawbacks of these materials are the higher prices, difficulties during processing and different mechanical properties compared to synthetic polymers (Prambauer et al., 2019).

The aim of this work was to evaluate four different biopolyesters towards their use in short-lived, bio-degradable geotextiles and to compare their properties to conventionally used polypropylene fibers.

2 MATERIALS AND METHODS

2.1 Materials

For fiber melt-spinning, polypropylene (PP) and four bio-polyester were used: Polylactic acid (PLA), Polybutylene succinate (PBS), Poly(3-hydroxybutyrate-co-3-hydroxyvalerate) (PHBV) and Polybutylene adipate terephthalate (PBAT). The brand names and providers of the polymers, as well as the diameters of the extruded fiber are listed in Table 1. Information about current polymer prices were obtained from literature (van den Oever et al., 2017).

2.2 Methods

The biopolymers were dried for two hours at 80°C prior to use. Afterwards the polymer fibers were produced by a melt spinning process with a Haake Rheocord 90 single-screw extruder with 19 mm screw diameter. The maximum barrel temperature for PP was set to 220°C and for the biopolyesters to 180°C. The fibers were produced with a spinneret plate with 69 0.5 mm diameter holes and air cooling.

Fiber tensile testing was carried out by a Zwick–Roell Z0,5 universal testing machine with a crosshead speed of 20 mm/min and a clamping length of 20 mm. For every sample and exposure time 10 replicates were tested. For the non-weathered polymer fibers a Weibull distribution of the failure strength and the according elongation was calculated. A two parameter Weibull distribution according to

$$F(x) = 1 - e^{-\left(\frac{x}{\alpha}\right)^{\beta}} \tag{1}$$

was applied, where *F(x)* is the distribution function, x is the strength or strain value, α is the scale parameter and β the shape parameter.

Table 1: Overview of used polymers and fiber diameters

Polymer	Provided as	Price (€/kg)	Fiber diameter (µm)
PP	Borealis PP HD120MO	1.0-1.2	340-360
PLA	NatureWorks Ingeo Biopolymer 2003D	1.5-2.0	315-370
PBS	Showa Denko Bionolle 1001 MD	4.0	380-430
PHBV	Tianan Enmat Y1000P	9.0-15.0	330-480
PBAT	BASF Ecoflex F Blend C1200	3.5	300-360

Artificial weathering was carried out in accordance to ISO 4892-2, process A, cycle 1, by an Atlas Weather-Ometer Ci 4000, which was equipped with a xenon lamp. The UV-wavelength was set between 300 and 400 nm and the cycle time was 120 min with alternating dry (108 min) and wet (12 min) periods. The fiber samples were irradiated in this cyclic pattern for 300, 500 and 750 h. Afterwards, tensile tests were carried out.

3 RESULTS AND DISCUSSION

3.1 Processing of biopolymer fibers

Polymer fibers with diameters between 340 and 415 µm were produced from PP, PLA, PBS, PHBV and PBAT granulate by melt spinning. Samples of the produced fibers are depicted in Figure 2. The production of PP fibers is a well-developed process and the fibers have been used for several decades in industry. This is not the case for the biopolymers used in this study. Therefore, the processability of the biopolymer fibers had an important impact on the material's potential use as geotextile. PLA is one of the best studied biopolymers on the market and there is some information available about textile fiber production (Gupta et al., 2007). Also in this study, PLA could be easily processed into fibers, due to a suitable melt strength and fast solidification time. PBS, PHBV and PBAT fibers have less industrial significance and only limited experience about fiber processing is available. PBS showed good processability and fibers could be produced in a similar way to PLA. In contrast, the processing properties of PHBV were very poor for the applied method and fibers with irregular diameters were produced. Even at low processing temperatures of 150-170°C, the material showed degradation effects and a poor melt strength. Furthermore solidification time of the fibers was too long resulting in fiber bundles sticking together. Compared to the other biopolymers, PBAT is a softer and more flexible material, which showed good melt strength. The solidification of the melt spun fibers was relatively long as well, however this problem could be solved by reducing the die temperature.

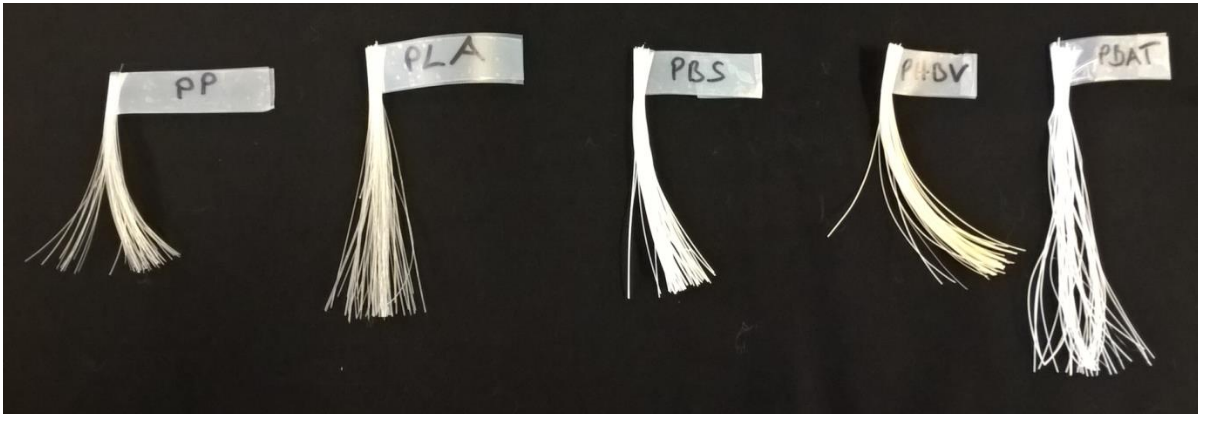

Figure 2. Melt-spun polymer fibers, made of PP and the four bio-polyesters. From left to right: PP, PLA, PBS, PHBV and PBAT

3.2 Mechanical properties of melt spun fibers

The melt spun fibers were characterized by tensile testing and a Weibull distribution of fiber fracture strength and according elongation was modeled. Especially the strength and elongation values of PP and PBS fibers varied over a broad range, which is depicted in the Weibull plots by a flat distribution function (Figure 3). The fracture strength of PBS ranges from 25 to 100 MPa, which indicates inhomogeneity of the produced fibers. The fracture stress distribution of PLA, PBAT and PHBV is more narrow indicating that more homogeneous fibers were produced. The average fracture stress (fracture probability of 0.5) for all polymers is between 60 and 80 MPa, except for PHBV, which shows a average fracture strength of only 30 MPa.

The elongations at fracture vary over several powers of ten for the different materials. Therefore the Weibull distributions are depicted on a logarithmic scale. PHBV fibers were characterized as very brittle and showed an elongations at fracture of only a few percent. In contrast, PP, PBS and PBAT show much higher elongations with average values of 1500-2000%. PLA is a more rigid material and shows an average elongation of 300%. It has to be noted that the fibers were not drawn prior to testing, hence the elongation is higher than for fibers, which are produced on industrial sites. Furthermore, it is also expected that the variation of mechanical properties within one fiber type can be reduced by applying a more uniform fiber production process.

As a result from tensile testing, it is suggested that the mechanical properties from PLA, PBS and PBAT fibers can compete with the fibers made from PP. Even though they show slightly reduced properties and a broader distribution, they are still in a suitable range for the production of geotextile fibers. The properties of PHBV were evaluated as too low in connection with such applications. Especially the high brittleness could cause problems with the product stability, as the geotextile needs to withstand some impact, e.g. from heavy rain drops or animals stepping on the mat. Also the brittleness of PLA could be too high and require some modifications of the material.

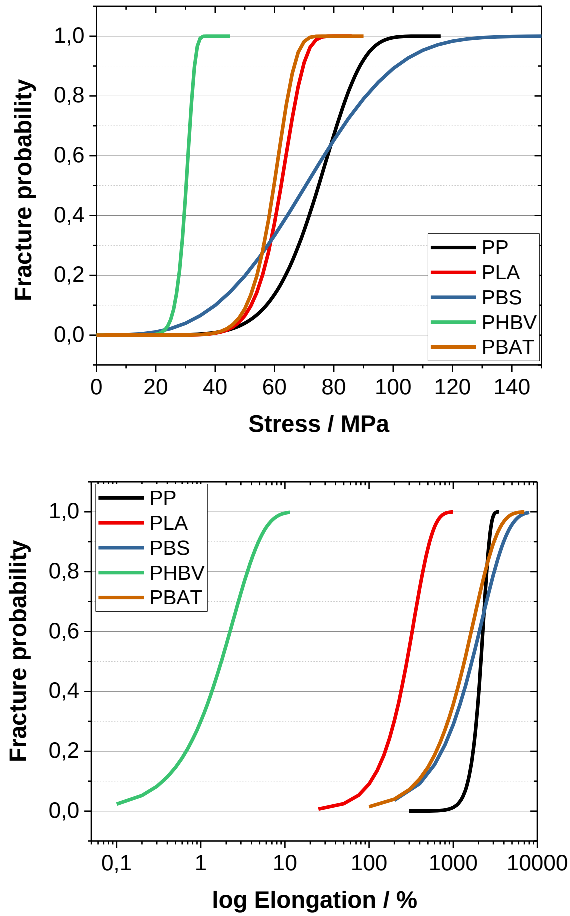

Figure 3. Weibull distributions of fiber fracture strength (top) and elongation at fracture (bottom)

3.3 Artificial weathering

All fibers were exposed to artificial weathering for 300, 500 and 750 h. By observing the influence of weathering on the fibers properties, information about the stability towards UV-light degradation and hydrolysis is obtained. Even though biopolymers are intended to degrade after a certain amount of time, they need to be mechanically stable for at least some months, in order to fullfill their function during plant growth. Therefore, the fibers were stored under accelerated weathering conditions, in order to evaluate their short-time stability.

As all biopolymers in this study were biopolyesters, hydrolysis is the major degradation mechanism and a certain susceptibility to moisture is given. In contrast, PP is highly hydrophobic, which means that no hydrolysis will occur. However, non-stabilized PP degrades rapidly by UV-light induced radical degradation mechanisms leading to disintegration of the material.

In Figure 4, the variation of mechanical properties with increasing exposure time is depicted. As expected, the mechanical properties of the non-stabilized PP degrade very fast and the fibers could only be measured until an exposure time of 500 h. The fibers became too brittle to be measured after longer exposure. Also PBS and PBAT showed a significant drop of mechanical properties after the first 300 h of exposure. Afterwards they either stabilized on the level or the further reduction of properties became less pronounced. The time of exposure showed no significant effect on the fracture strength of PLA, but a reduction of elongation was recorded. The elongation at fracture was significantly reduced and was below 100% for all fibers after 750 h of exposure. The fiber's embrittlement indicates that a low concentration of stabilizer might be necessary for the biopolymers in order to maintain their function during plant growth. Ideally, the stabilizer is also of bio-degradable or bio-resorbable nature, in order to avoid environmental contamination after the polymer has degraded. Further modifications of the material, e.g. by blending could also lead to a reduction of brittleness and an increase of initial stability.

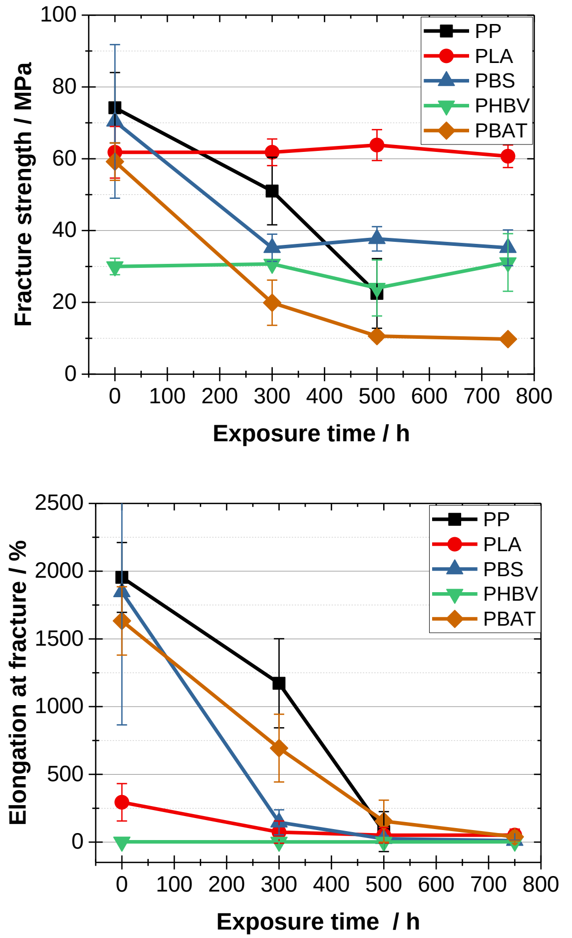

Figure 4. Mechanical properties of polymer fibers in dependency of exposure time: effect on fracture strength (top) and elongation at fracture (bottom)

4 CONCLUSIONS

Short-lived geotextiles find application as protection covers against soil erosion and revegetation aids. By reducing runoff on soft soils and slopes, plant growth is promoted until a natural green cover has established and the vegetation can take over the protective function. By applying bio-degradable (short-lived) geotextiles, laborious material recollection is obviated and there is also no agglomeration of non-degradable polymers and additives in the ground.

In this study four different biopolyester fibers were produced and evaluated towards their suitability for being used in short-lived geotextiles. The fibers were characterized by tensile testing and the mechanical properties were compared to non-stabilized PP fibers. The fracture strength of most biopolyesters were within the range of PP indicating the potential for geotextile applications. PBS and PBAT also showed high values for the elongation at fracture, while the values for PLA were significant lower. PHBV gave the lowest results of all tested polymers and together with the currently high price level it was evaluated as less suitable for the application in mind.

After exposure to artificial weathering the elongation at fracture of all fibers decreasing, indicating embrittlement. PLA showed no significant change in fracture strength with increasing exposure time, however it also became less ductile. The results obtained by artificial weathering suggest that modification, either by stabilization or blending, is required in order to improve the material's initial stability. However, this will be the subject of further research on the topic.

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