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Review

Biodegradable geotextiles – An overview of existing and potential materials

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ABSTRACT

Geotextiles are a group of mostly thermoplastic polymers, which are processed to flexible material sheets, and are installed on various landscapes for reinforcing or protective purposes. Most applied materials in the field are non-degradable polymers, such as polyolefins or polyesters, which can implicate environmental problems concerning soil pollution and accumulation of micro plastics. Because of these drawbacks, for some applications time-consuming re-collection of the material becomes necessary. Hence, the development of more environmentally friendly and biodegradable geotextiles is of interest for several application purposes. In this review biodegradable alternatives to the conventional polymeric geotextile fibers are discussed. In general, there are two material classes available, which are natural fibers and biodegradable polymers. While there is already quite a number of natural-fiber-based geotextiles available on the market, the idea of applying industrial biopolymers for this purpose is relatively unexplored. Geotextile fabrics, made of plant fibers, represent a promising approach and were already successfully installed in several applications. However, the use of natural fibers also entails some limitations regarding water uptake and stability. Therefore, the potential use of a different material class, which comprises degradable, thermoplastic biopolymers, is discussed in this overview as well. There is only little information available on the use of these biopolymers in connection with geotextiles, thus their suitability regarding biodegradation, price and mechanical properties were evaluated.

1. Introduction

Geotextiles belong to the group of geosynthetics, which are permeable and flexible material sheets and mainly consist of thermoplastic polymers, such as polypropylene (PP) or polyester. Geosynthetics are produced in various designs, for example as membranes, grids, nets or foams. Their functionality conforms to a whole range of applications, which are mainly in the field of civil and environmental engineering. From all geosynthetics, geotextiles represent the most important category and they are used in various foundations serving different purposes. Depending on the application in mind, woven and non-woven geotextiles can be installed on or inside the ground. Non-woven fiber sheets, which account for the biggest share of geotextiles, are preferably used in filtration and drainage application due to their 3-dimensional structure, which results in high porosity and permeability with varying pore sizes. In contrast, woven fabrics exhibit superior mechanical properties and therefore find application in the field of soil reinforcement and stabilization (Li et al., 2016; Ogbobe et al., 1998). The typical functions of geotextiles, as listed in literature, are (i) drainage, where redundant water is gathered or removed from the soils or walls, (ii) separation, in order to avoid the commingling of two different foundations with different properties, as it is frequently required in road and railway construction, (iii) filtration, where particles are retained in the geotextiles, while the water passes through, (iv) reinforcement of an unstable or highly exposed environment and (v) protection against mechanical damage (Rüegger, 1986). In Fig. 1, some examples for the potential application of geotextiles in order to protect or reinforce the given foundation are depicted. The demand for geotextiles on the market shows a tremendous increase and currently over 1400 million square meters of geotextiles are used every year. At the moment, only 2% of this amount originate from a natural fiber source, though it is estimated that in approximately 50% of all geotextile applications, natural fibers and biopolymers could replace the synthetic materials (Gupta, 1991; Methacanon et al., 2010; Wiewel and Lamoree, 2016).

PP is the most frequently used material in connection with geotextiles, followed by polyethylene terephthalate (PET) and polyethylene (PE). Also different polyamides and chlorinated polymers, such as polyvinyl chloride (PVC), contribute with a small fraction to the world wide geotextile production. Even though the mentioned polymers are

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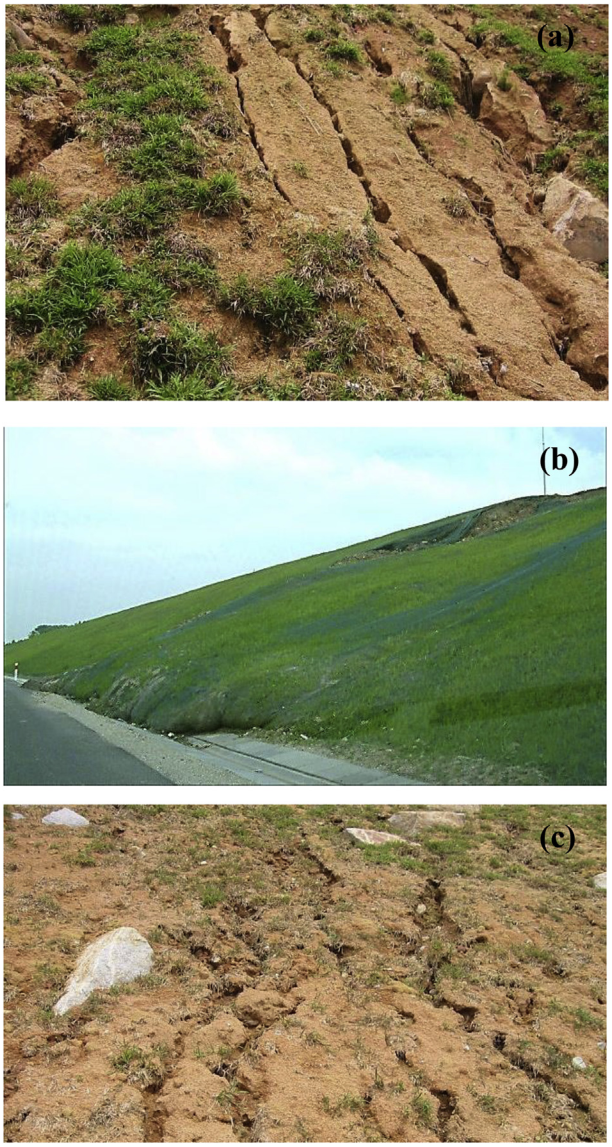

Fig. 1. Fields of application for reinforcing and protective geotextiles: (a) sliding and erosion on steep slopes, (b) landslide at a slope of ca. 25°, (c) floor erosion due to heavy rainfall causing loss of vegetation (Gröner and Roduner).

basically non-degradable materials, disintegration of the polymer by various chemical and physical fragmentation mechanisms can be observed. Disintegration of polymers is triggered by several environmental influences, such as wind, moisture, friction and UV-light radiation and can lead to an accumulation of micro plastics in the ground. The exact degradation mechanism and rate strongly depends on the ambient conditions and polymer in use. Especially, temperature is an important factor, which usually accelerated every degradation mechanism. Furthermore, most polymers show UV-light absorbance at a wavelength between 300 and 400 nm causing radical initiated oxidative degradation, as frequently observed in PE and PP. Besides that, in polyesters a degradation due to hydrolysis is most likely to occur. Also biodegradation, caused by fungi or bacterial microorganisms, radiation and material swelling have a negative effect on the durability of the polymers. In order to avoid this material deterioration in long-term applications, additives such as UV-light and thermal stabilizers are added to the polymers. For instance, carbon black is added up to 3 wt.% for minimizing or delaying the UV-light induced degradation process in various polymers. However, additives and other processing aids tend to leach out of the material after a certain time period and accumulate in the surrounding floor resulting in environmental pollution (Hsuan et al., 2008; Wiewel and Lamoree, 2016). As mentioned before, the second environmental aspect is the material degradation itself and its accumulation, caused by the fragmentation of the geotextile fibers. Particles below 5 mm diameter are defined as micro plastics, which are related to several problematic issues especially in the marine or alpine environment, where several species can ingest these particles. This needs to be considered, when designing geotextiles for long-term applications together with a possible recycling route for re-collected materials after they reached the end of their service life. Permanent floor reinforcements are an example for long-termed geotextile applications, where the material needs to stay intact for several decades. At the moment, materials for such purposes are produced from synthetic polymers, which are sufficiently protected by additives against environmental degradation (Wiewel and Lamoree, 2016). Besides, these materials are also naturally protected against UV-light degradation as they are being used underground.

For several geotextile applications longevity and durability are important factors, in order to fulfill their function in soil reinforcement and protection. However, also geotextiles with a much shorter life-span are designed, which are supposed to degrade after a certain time period. These materials are used for preventing soil erosion until the seeded vegetation can take over this function or the floor is sufficiently consolidated. Thus the geotextile should degrade after a couple of months or years into environmentally compatible components, which obviates the need of material re-collection (Mwasha, 2009). For this sort of geotextiles, natural fibers but also other biodegradable polymers are an option. Even though there is a certain demand on this short-lived biodegradable geotextiles, they are still rarely used in commercial products. In literature, there is a number of scientific studies available, which deal with the topic of biodegradable geotextiles. Most of them focus on natural fibers, such as jute, coir or sisal fibers. Natural fibers with high cellulose contents initially exhibit high mechanical strength, but also early aging effects were observed, which significantly decrease in the textile's integrity and efficiency. Together with natural variations in fiber properties, difficulties during the spinning process and varying environmental influences, lifetime prediction of natural fiber geotextiles becomes challenging (Ghosh et al., 2009; Methacanon et al., 2010). On steep slopes (> 45°) the efficiency of natural fiber geotextiles is not uniformly confirmed. Furthermore, natural fibers have higher surface weight compared to synthetic fibers and can gain additional weight by water absorption, which increases the initial dry mass up to several hundred percent. A firm installation of the geotextile with good soil contact on steep slopes is complicated by this circumstance (Álvarez-Mozos et al., 2014; Gröner and Roduner). In terms of bio-degradability, also a range of industrial biopolymers are a possible option for short-lived geotextiles. Materials such as thermoplastic starch (TPS), polylactic acid (PLA) or different polyhydroxyalkanoates (PHAs) are well-known from the field of packaging where biodegradation of polymeric materials is an issue as well. These materials could be the base for degradable geotextiles and serve in applications, where the property profile of natural fibers is insufficient. Uniform thermoplastic geotextile fibers, which show a desired degradation rate, can be produced by melt spinning processes and by combining different polymers, fibers and filler materials. This material option has been widely neglected in literature so far and there are only a very limited number of studies available, which deal with these materials in connection with geotextiles (Bipin, 2011; Jeon, 2016; Kumar and Das, 2018; Wiewel and Lamoree, 2016).

The aim of this review article is to give an overview of already existing biodegradable geotextiles and to discuss other biodegradable polymers which could be used in the future production of geotextiles. Further, the review discusses the requirements on short-lived geotextiles and how these requirements can be met by the newly emerging material class of biodegradable polymers. It was focused on the availability, degradation mechanisms, composition and mechanical