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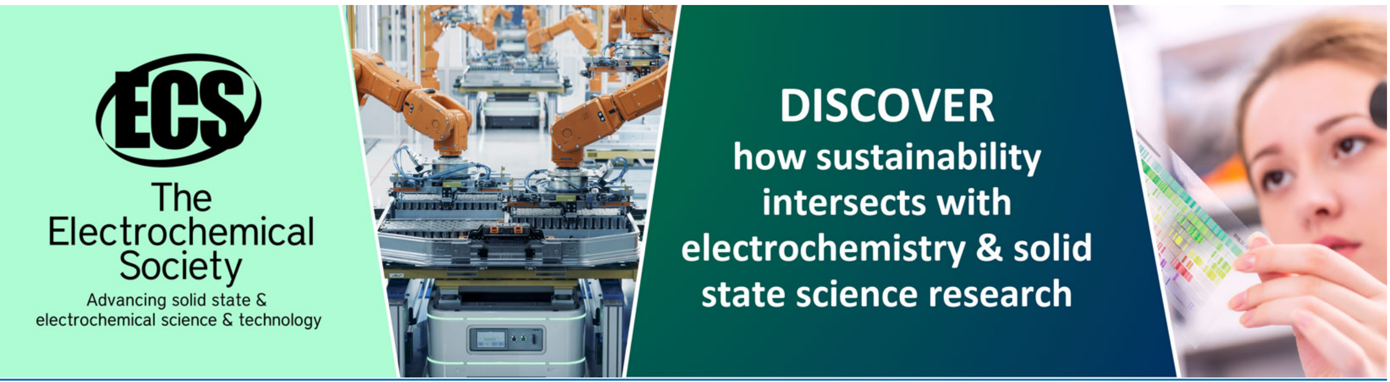

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Application of recycled fibres and geotextiles for the stabilisation of steep slopes

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Abstract. The recycled fibres and textiles were used for the protection of the steep slope exposed to intensive rill erosion. One part of the slope was protected with the geotextiles formed from the meandrically arranged thick ropes containing a nonwoven manufactured from a blend of recycled natural and synthetic fibres. For the protection of the other part, the recycled polyester fibres mixed with the covering soil were applied. After the installation, the behaviour of the slope was monitored and the efficiency of both techniques was compared. It was stated that both, the geotextiles and the loose fibres randomly distributed on the soil prevent washing away the soil particles and protect the slope from sliding. It was revealed that the recycled fibres can be satisfactory utilized for the efficient protection of the slope against erosion and sliding.

1. Introduction

Construction of earth structures and exploitation of open mines lead to the formation of slopes prone to land sliding and endangered by surface erosion caused by water. Due to the high risk of landslide and erosive damage, the protection of the slopes to ensure their stability is highly desirable.

Different methods are used for the stabilization of the slopes. One of the techniques, often applied for several decades, involves the application of the geosynthetics. Geosynthetics have high biological and chemical resistance, non-corrosiveness, lightness and relatively low price. They are usually supplied as rolled products which can be easily transported and spread on the slopes. The installation of the geosynthetics is easy and does not require a lot of manpower or the use of heavy, specialized equipment. The installed geosynthetics provide an aesthetic look of the protected objects [1-3].

Different products including geotextiles, geomatts, geogrids and geomembranes are offered on the market. The variety of available products allows the selection of products most suitable for the local circumstances.

In addition to the known products which have been used for many years , new geotextiles were invented few years ago. The innovative geotextiles were built from meandrically arranged thick ropes which were connected into segments with additional linking chains. The geotextiles were successfully used for the stabilization of the slopes prone to land sliding in the gravel pit and disused lignite mine, as well as for the protection of the drainage and road side ditches [4-7].

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For the manufacturing of the ropes, the Kemafil technology and various materials (easily available on the local market) were useded [5]. It was revealed that the pre-consumer or post-consumer textile wastes can serve as a valuable raw material for the manufacturing the geotextiles. The production of geotextiles extends the life of the fibres and is an interesting alternative to troublesome methods of waste textiles disposal.

The second technique for the stabilization of slopes consists in reinforcing the soil with randomly distributed natural or synthetic fibres. The fibres mixed with the soil serve as natural plant roots, which improve the strength of the soil and the stability of natural slopes. The technique was used for various civil engineering structures such as pavement layers, retaining walls, railway embankments, as well as for the protection of slopes, foundation engineering and anti-earthquake geo-structures [8].

The reinforced soil mixture sprayed onto the eroded, cut slopes can be used as an infilling of the erosion gullies. This can be an effective repair method, especially in low cohesion materials like sand, dispersive clays or soils containing gypsum [9]. The impressive example for the implementation of this technique was the use of the polypropylene fibres for the stabilisation of a huge embankment constructed of residual fat clays in Texas [10].

During the investigations, both of the above mentioned techniques were used for the protection of the steep slope exposed to intensive rill erosion. The efficiency of each method and their combination in the protection of the slope was analysed.

2. Materials and methods

2.1. Site characteristics

The investigations were performed in a terrain located in the foothills of the mountain range Beskid Maly, in the northeast suburbs of Bielsko-Biala (Poland). The area is formed by meadows spread on the wide and gently sloping northbound hills.

In order to start an economic activity on the hill, three flat terraces were artificially formed (Fig.1a). In this way, steep slopes were generated between terraces. The slopes had the length of 5.5 m and the inclination of 1:1.5. On the slopes three types of soils were identified. The upper part of the slopes is a backfill and is formed from clay of intermediate plasticity (CI) with water content w = 18.4 %, liquid limit wL = 38.2 %, plastic limit wP = 16.7 % and plasticity index IP = 21.5 %. In the middle part of the slope, there is the clay of low plasticity (CL) with w = 20.4 %, wL = 34.7 %, wP = 16.9 % (IP = 17.8 %) and in the lower part of the slope, the gravelly clay (CG) with w = 20.4 %, wL = 45.1 %, wP = 20.8 % (IP = 24.3 %) were stated.

a/

b/

Figure 1. The experimental site in the suburbs of Bielsko-Biala: a/ overall view; b/ rill erosion on the surface of the slope

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The slopes were exposed to the intensive rill erosion caused by the streams of water flowing from the one to the next terraces (Fig.1b).

For investigation purposes, experimental plots with a width of 2 m were separated on the slope (Fig.2). Four plots were protected with the geotextiles built from the segments of ropes arranged in a meander-like pattern. Three of them were covered with the soil mixed with different amounts of polyester fibres. As a reference, one plot was covered by the soil without fibres. Similarly, three plots not protected with the geotextiles were covered with the soil mixture with the polyester fibres and one plot was covered with the soil without fibres.

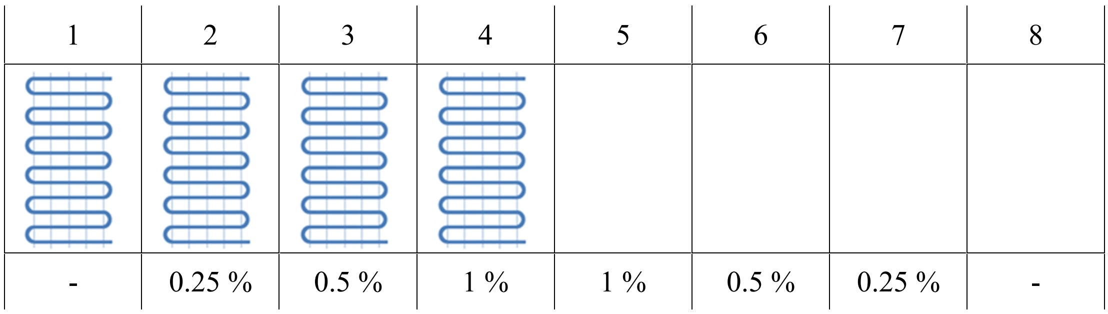

Figure 2. Schematic layout of the experimental plots.

2.2. Materials

For the manufacturing of the geotextiles, waste strips of the nonwoven from recycled fibres supplied by Amanda (Bielsko-Biala, Poland) were used. The nonwoven was made from blended recycled natural and synthetic fibres obtained by shredding of the post-consumer textile wastes. The nonwoven was produced by means of the stitch-bonding Maliwatt technique. The web of the recycled fibres were stitched by the polyester multifilament thread with a linear mass density of 148 dtex. The parameters of the nonwoven are presented in Table 1.

Table 1. Parameters of the nonwoven used for the production of the ropes

Thickness [mm]	Mass [g/m^2]	Tenacity [kN/m]		Elongation at break [%]		Static puncture resistance [kN]	Dynamic puncture resistance [mm]
		warp	weft	warp	weft		
3.0	265	3.3	0.9	29	34	0.41	35

The strips of the nonwoven were bounded into thick ropes sheathed by the polypropylene twine by means of the Kemafil technology (Fig.3). The ropes with the diameter of 100 mm were arranged in the meandrical pattern. The subsequent turns of the meandrically arranged ropes were connected with the regularly spaced five chains into segments with the lengths of 6 m and the width of 2 m. To form the chains, the polypropylene three-wire twine from fibrillated fibres with the linear density of 310 dtex was used.

Figure 3. The Kemafil rope manufactured from the nonwoven made from blended recycled fibres.

The soil was reinforced with the staple polyester fibres obtained from the recycling of bottles. The fibres were supplied by Elcen (Gdynia, Poland). The fibres had the length of 64 mm and the linear density of 15 dtex.

For covering of the plots, the top soil clay of low plasticity (CL) with w = 28.4 %, wL = 46.5 %, wP = 19.5 % and IP = 27 % was used.

2.3. Measuring methods

The basic parameters of the nonwoven: thickness and mass per square meter were measured in accordance with the PN-EN ISO 9863-1:2016-09 and PN-EN ISO 9864: 2007 standards. For the measurements, the thickness gauge for geotextiles D-2000-G2 (SCHMIDT Instruments, Germany) was used. Additionally, the mechanical parameters of the nonwoven were determined.

The measurements of the tensile strength and elongation at break were carried out in accordance with the Polish standard PN-EN ISO 10319:2010 by means of KS50 Hounsfield tensile machine. The static puncture resistance was determined by CBR test, in accordance with the Polish standard PN-EN ISO 12236:2006. The dynamic puncture resistance was measured by cone drop test, in accordance with the Polish standard PN-EN ISO 13433:2006.

The parameters of the polyester fibres: length and linear density were determined in accordance with the standards PN-ISO 137:2000 and PN-ISO 6989:2000.

Water content, liquid and plastic limits of soils were determined in accordance with the British standard [11-12]. In order to determine the liquid limit, the Casagrande apparatus method (four-point method) was applied.

3. Results

3.1. Installation of the geotextiles on the slope

On the plots protected with the geotextiles, the segments built from the meandrically arranged ropes were spread on the slope, anchored in the crown and fastened to the surface with the steel "U-shaped" pins (Fig.4). The pins were hand-hammered to a depth of approximately 40 cm.

After the installation, the protected plots, as well as the plots without the geotextiles, were covered with the 20 cm layer of the soil mixed with the polyester fibres. The mixtures of the soil and fibres, with fibres accounting for 0.25%, 0.5% and 1% of the dry soil weight, were prepared. The mixtures were prepared by spreading the right amount of fibres on the soil layer and then covering them with the additional layer of the soil. For mixing, a road recycler machine was used (Fig.5a). The mixed soil was transferred to the slope and evenly distributed on its surface. Finally, the covering layer was compacted by the excavator bucket (Fig.5b). Few days after the installation, the grass seeds were sown on the surface of the slope.

a/ b/

Figure 4. Installation of the meandrical geotextiles: a/ the segments spread on the surface of the slope; b/ fastening of the ropes

a/ b/

Figure 5. Covering of the slope with a layer of the soil mixed with polyester fibres: a/ mixing of the fibres with the soil; b/ formation of the covering layer on the slope

3.2. Monitoring of the slope

In first week after the installation, it was stated that the geotextiles installed on the slope as well as the fibres mixed the soil provide immediate protection of the slope against erosion. During the first rains that fell before grass seeds germination, no erosive grooves on the surface of the slope were detected. In the first period of exploitation, the settlement of the soil located between the turns of the ropes was observed on the plots protected with the geotextiles. Simultaneously, the ropes arranged laterally on the slope formed a network of micro-dams which slowed down the runoff of water. The dams stopped the soil particles detached from the surface and their transport down the slope with the water stream was impeded.

On the plots reinforced with the fibres randomly distributed in the soil, the fibres formed a structural mesh, which held the soil particles. Moreover, the fibres absorbed certain part of energy from the rain drops or flowing water, thus, preventing the washing away of the soil particles.
In the following months the monitoring of the slope will be continued. The influence of the installed geotextiles on the greening of the slope will be evaluated. Simultaneously, the effect of the fibre concentration on the stabilization of the slope will be discerned.

4. Conclusions

The meandrical geotextiles made from the recycled fibres provide efficient protection of the slope against erosion. The subsequent turns of the ropes prevent the soil from sliding down the slope and form bag-like structures which can keep large amounts of the topsoil on the slope, even in humid conditions. The fibres mixed with the clay soil considerably improve the strength of the soils and prevent slope sliding.
The fibres and the geotextiles ensure the protection of the slope immediately after the installation, before the greening of the slope and the development of grass cover.
For the protection of the slope, the recycled polyester fibres as well as nonwoven made from the recycled fibres can be utilized. The use of the recycled fibres in the protection of slopes can contribute to the rational textile waste management.

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