Advanced multiple leno woven geogrids with enhanced properties

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ABSTRACT: Geogrids are widely used in reinforcement of soil in various geotechnical and civil engineering applications. For road and cement reinforcement, the open grid structures further enhance and facilitate the bonding of the woven textile structure with the surrounding material (asphalt, cement matrix or soil). Existing geogrids such as biaxial warp-knitted fabrics and leno woven fabrics have limited shear strength or production speed. In this work a process is presented that uses a full cross rotating disk-type leno-technology, that is being developed in cooperation with the German supplier for weaving accessories Gebr. Kloecker GmbH allowing the twisting of warp yarns to entangle inserted weft yarns with rotation angles of up to 720°. The twisting of the warp yarns leads to an increased compaction of the warp yarns and hence to a decreased coating material consumption. Furthermore, due to the twist of the warp yarns, an increased shifting strength can be achieved by increasing the yarn friction at the points of entanglement; as a result of the robustness of the grid structure the subsequent process steps such as coating, as well as the handling by the user are promoted. Within this work the results of producing and testing multi-rotation leno weaves with high mesh width of at least 20 mm, are presented.

Keywords: Geotextiles, Geogrids, Leno woven, Weaving

1 INTRODUCTION

Geotextiles are planar textiles, which are primarily used as building materials for the civil and hydraulic engineering sector, infrastructure industries and geotechnical safety works (Koerner, 2012). Geotextiles are frequently provided with an additional coating to increase the resistance to mechanical damaging, biological and chemical degradation, improve the corrosion behaviour and thus increase the long-term stability in the soil.

Within the project „GeoLeno“, a weaving technology is developed at the „Institute for Textile Technology of RWTH Aachen University“, in close cooperation with the company „Gebr. Klöcker GmbH“, as part of the „Central Innovation Program for SMEs“ (ZIM) funded by the Federal Ministry of Economics and Technology (funding codes KF3414614PK4 and KF2072203PK4). This weaving technology allows the production of multi-leno woven fabrics by means of disc-shaped shifting elements. The use of multi-leno woven fabrics offers a high potential for increasing the strength and reducing the coating thickness of the textiles. Geogrids with a grid spacing width up to 18 mm are producible with the developed technology. The project includes, inter alia, the examination of the mechanical properties, mass receptiveness and penetration depth of the coating material into the yarns of the fabrics. Figure 1 shows exemplarily the crossroad point of a coated multi-leno woven fabric, as used in the geotechnology.

Figure 1. Coated multi-leno woven geogrid

2 MATERIALS AND METHODS

A total of 24 samples were prepared for analysis, which arose by 3 variable parameters. Thus, the samples differ in the combination of the fineness, the twisting angle of the warp yarns and the coating material used. Besides, polyester yarns (Diolen 174S) with a fineness of 1100 dtex and 3300 dtex were used. The twisting angles were varied between 720°, 360° and 0°. The coating materials used were customary polyvinyl chloride (PVC) and styrene-butadiene rubber (SBR) coatings, which differ in viscosity in order to characterize the mass absorption, concerning twisting angle and viscosity. A highly-viscous (FolcoSol K-ST 6097/2), semi-viscous (FolcoSol K-ST 6097/8) and low-viscosity (Litex S 9076) dispersion were examined. In addition, an non-coated reference sample (KB) was produced for each parameter combination. Table 1 summarizes the examination area.

Table 1. Characteristics of the process parameters.

Twisting angle	Fineness	Viscosity	
0°	1100 dtex	Highly-viscous (HVB)	4300-5000 mPa s
360°	3300 dtex	Low viscosity (NVB)	< 300 mPa s
720°		Semi-viscous (SVB)	1500-2500 mPa s

By comparing the masses of the coated and non-coated samples, it could be determined how much coating material was absorbed by the filaments. Furthermore, the samples were examined by optical microscopy and tensile tests were conducted in accordance to DIN 13934–1:2013.

3 RESULTS AND DISCUSSION

3.1.1 *Results of the gravimetric examination*

The gravimetric examination was conducted on 520 mm x 320 mm samples, which were prepared according to the various parameters, by means of a high-precision scale. It can be seen that the quantity of mass absorbed by the filaments is highly dependent on the twisting angle. As the twisting increases, the penetration depth decreases, which results in a lower absorption of coating medium. Thus, the mass of the samples decreases with increasing twisting. As a result of the larger penetration depth of the coating medium into the fiber, the 360°-twisted samples are on average 10 %–15 % heavier than the 720°-twisted samples. In addition to the twisting dependency of the mass acceptance, there is still a dependency of the fineness. It was found that filaments with a fineness of 3300 dtex absorb on average three times as much coating material as yarns with 1100 dtex. Figure 2 shows exemplarily the absorbed mass with different coating material and twisting angle with a length-related mass of 1100 dtex.

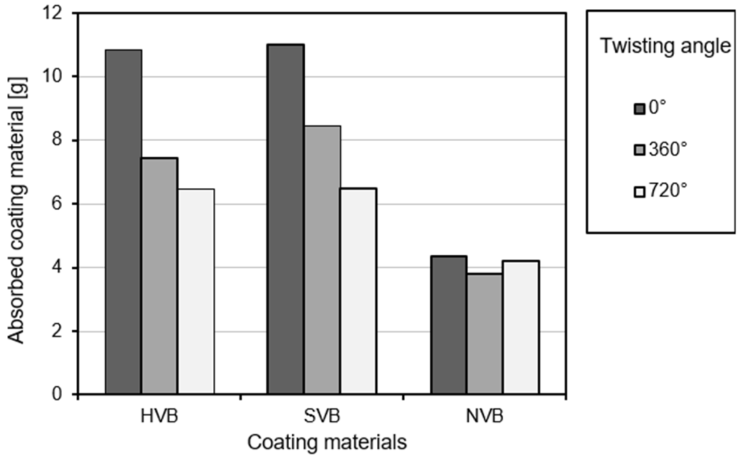

Figure 2. Absorbed coating material of 1100 dtex yarn.

The low-viscosity (NV) samples with 1100 dtex absorb approximately half the coating material compared to the SV- and HV- samples. The semi-viscous coating material penetrates better into the filaments then the highly-viscous coating material. However, the differences in the mass uptake between the semi- and highly-viscous coating material (average deviation of 14 % at 1100 dtex and 29 % at 3300 dtex) are way lower than the differences to the low-viscosity coating. When using the low-viscosity coating, the yarns absorb an average 0.2 times (1100 dtex) respectively 3.7 times (3300 dtex) more coating mass compared to those with the semi- and highly-viscous coatings.

The amount of coating absorbed in the 3300 dtex samples (Figure 3) is similar to the increases at 1100 dtex described above.

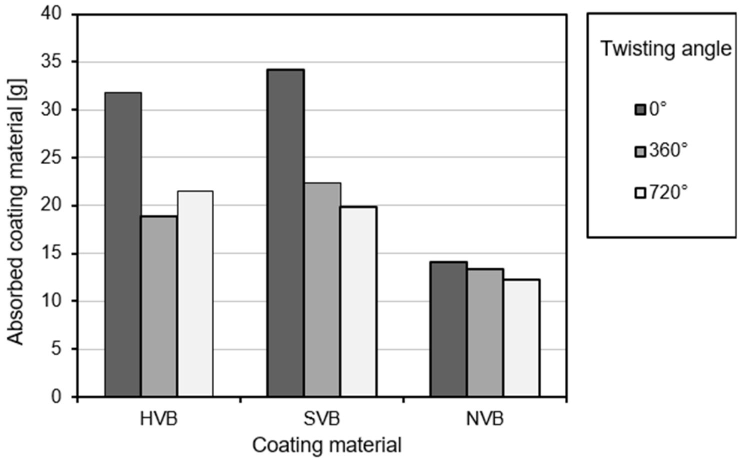

Figure 3. Absorbed coating material 3300 dtex.

The mass uptake of the low-viscosity coated samples is a factor of two among the highly viscous coated samples. The influence of the twisting angle is more pronounced at the samples coated with highly viscous material than at the ones with low-viscosity coating.

3.1.2 *Results of the microscopic examination*

Two different microscopic examinations were performed. In the first method, the external characteristics of the gratings were examined by means of a light microscope and a magnification of 1.6 – 2.0. With the second method, the cross-sectional area of the warp yarns was examined. For this purpose, samples with dimensions 20 mm x 30 mm (20 mm in the direction of the warp yarns) were embedded in a resin. In order to examine the cross sectional area, the sample was then abraded perpendicular to the warp yarns. The imaging was performed with 100-fold magnification.

For all 0°-samples, there was a visible penetration of the coating material into the center and the individual fibers were completely sheated by the coating material. This is also visible in the material inclusions and clusters in the center. Notable differences in fiber fineness were not apparent.

Figure 4 shows the microscope images for 1100 dtex taking the applied twists and the coating materials used into account.

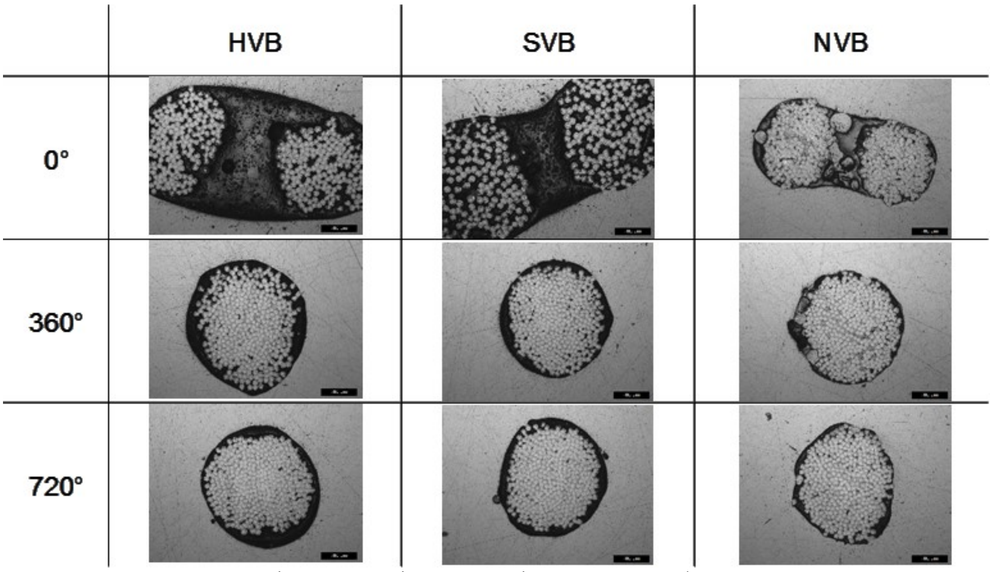

Figure 4. Microscope images 1100 dtex.

The 360°-samples coated with the highly- and semi-viscous material of both fiber fineness showed a large number of air inclusions, which are recognizable as black dots between the strands. In this case, no penetration of the coating material to the fiber core took place, instead the coat was thicker than in the 0°-samples.

Analyzing images of the 720°-samples with HV and SV coating, it can be noted, that the coating material seldom penetrates behind the first strands. There are only sporadic air pockets recognizable inside. A clear enlargement of the cross-sectional area of the cohesive dry filaments can be seen. The coating mantle had a thickness similar to the 360°-samples.

The 720°-NV samples show many air inclusions similar to the 360°-samples, which can be seen in the complete cross-section. Air bubbles at the surface occur with a fineness of 1100 dtex as well as with 3300 dtex. At some points, larger deposits occurred, which expanded during hardening. The coating thickness around the yarns was comparatively small.

With increasing twisting, a decreasing penetration depth of the coating material could be detected, whereby the yarns took up less coating material.

3.1.3 *Results of tensile test*

The tensile test were carried out in accordance with DIN 13934. The gauge length was 200 mm and the biasing force was 0.5 N. The sample width was set to 60 mm, with three warp yarns per sample. The test speed was 10 mm/min. Seven samples were tested for each tissue. All of them were air-conditioned according to ISO 139. The determined tensile strengths of the samples with 1100 dtex are in a range from 602 MPa to 848 MPa as shown in Figure 5.

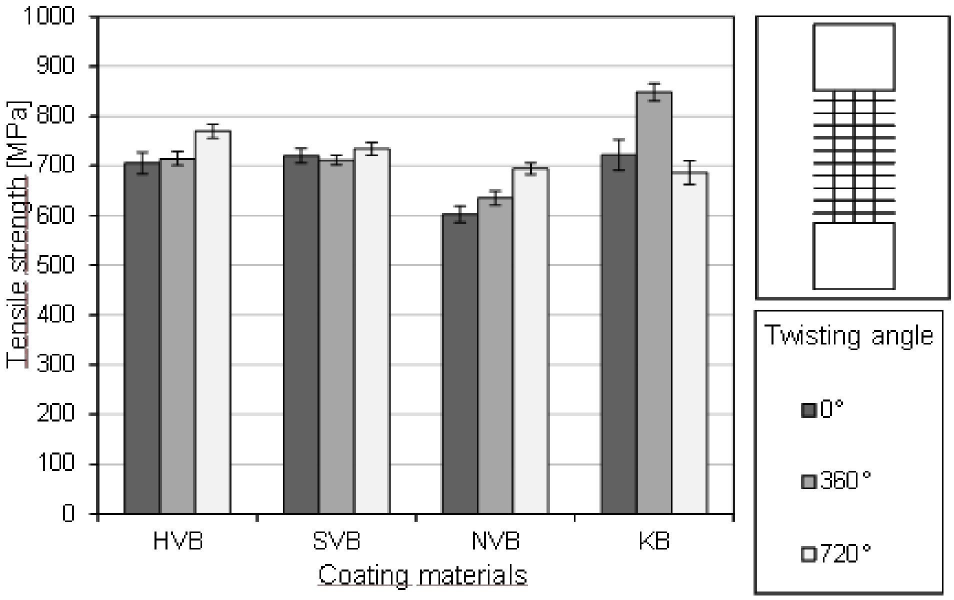

Figure 5. Tensile strength 1100 dtex.

The twisting of the warp yarns had a negative effect on the tensile strength. Due to manufacturing conditions, the three supporting warp yarns don't have the exactly same pretension, which results in an uneven distribution of the tensile force on the yarns. Increasing twisting leads to a decrease in the extensibility of the filaments and thus to an uneven distribution of force, resulting in a decrease in tensile strength. The yarns of the 0°- samples without any coating are more flexible and distribute the introduced force more evenly. The non-coated 720°- samples have the least tensile strength and elongation values due to the twist.

A further decisive factor influencing the tensile strength of the coated samples is the penetration depth of the coating material. An increasing penetration depth resulted in a decreasing tensile strength. As a result of the penetration of the coating material, the stiffness of the samples is increased and an uneven force distribution is favored. Due to the lower penetration depth, the twisted samples have a dry area in the cross-section, in which no coating material has penetrated.

This dry area causes a greater elongation, consequently allowing a good force distribution. Because of this, a lower penetration depth of the coating material has a positive effect on the tensile strength. Accordingly, the 720°-samples have a higher maximum tensile strength than the 360° samples, due to the larger dry cross-section. Increasing the fineness has a slightly negative effect on the tensile strength. Tripling the fineness results in a merely increased tensile strength by an average of 2.8, this corresponds to a loss of tensile strength of 7 %. Further, a dependency of the tensile strength on the selected coating material and its properties was shown. Since a PVC dispersion was applied on the HV and SV samples, these have similar material properties, as opposed to the NV samples using a SBR dispersion. Thus, the NV-samples have an average 11 % lower tensile strength than the HV- and SV-samples.

3.1.4 *Stepped isothermal method*

In order to evaluate their long-term deformation properties, the creep tests are used to predict properties for a long period (Hsiehl, 2008). Generally, the creep tests methods include conventional creep test and accelerated methods allow activating the deformation processes by temperature, e.g. a stepped isothermal method (SIM). This method is based on the viscoelastic properties of the polymers consisting in their ability to creep under the temperature action.

In this study, for the reference and coated rovings samples the creep properties were tested by SIM test at loading level of 50% of the tensile strength. The results for SIM test are shown in the Figure 6. The results obtained showed that the coating had little effect on the creep behavior. The dashed red line shows the creep deformation without accelerating by temperature. Heating the sample in a thermal chamber allows to accelerate creep and within a short period to obtain a curve for longer times.

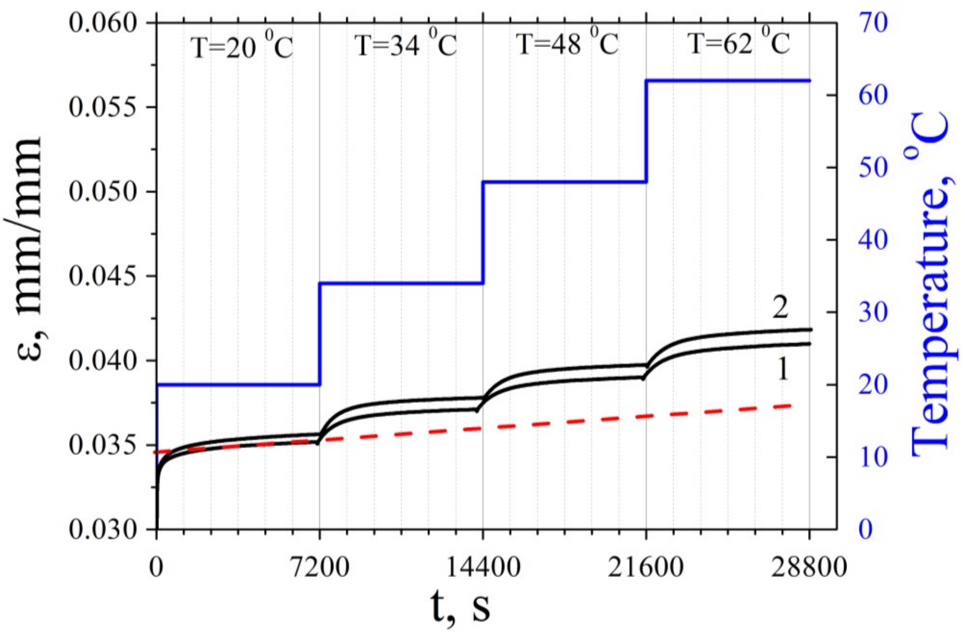

Figure 6. Stepped isothermal method: 1- reference polyester roving of 1100 dtex, 2 – PVC coated polyester roving of 1100 dtex.

4 CONCLUSIONS

The results show clear design possibilities of coated mutli-turn fabrics by intelligent parameter selection. By using certain coating materials, tensile strength and stretch resistance can be modified. The weight increases, on the other hand, strongly depend on the rheological properties, whereas the twisting angle significantly influences the mechanical properties of the multi-turn fabrics. A modification in the yarn fineness can have a strong effect on the mechanical properties as well as on the absorption of the coating mass.

A potential material saving is given by the use of low-viscosity coating materials. As indicated by the weight increases, a 75 % - 85 % tensile strength, compared to the non-coated samples, can still be achieved with up to 75 % less mass, by using low-viscosity coatings. Mass absorption and tensile strength provide a high potential for optimization. Since less coating material is absorbed with increasing twisting angle, further material saving can be achieved here. When selecting the appropriate twist, a compromise between material saving and penetration depth must be found.

Further testing of the protective functions of the coating materials has to be carried out, in order to contextualize the results. It has to be clarified whether PVC dispersions have the same protective functions as SBR dispersions. For a closer inspection of the correlations mentioned, further investigations with a larger variation are indicated.

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