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Geotextile nonwovens made of flax

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ABSTRACT: It was the main aim of a research project "Development and testing of the applicability of flax fibres as geotextile nonwoven fabrics and composite materials for earth construction and hydraulic engineering" supported by the Federal Government to produce mechanically bonded nonwoven fabrics and composite materials from flax fibres using the needle-punching and knitting technique and to examine the use of such products for geotextile application cases in earth construction and hydraulic engineering. The present contribution shows select results.

1 INTRODUCTION

In general earth construction geotextiles, made of natural raw materials, can e.g. be used for slope and erosion protection, for the restoration of ski courses and slopes, as carrier material for roll grass and grass mats with seeds. Especially for the subnatural hydraulic engineering rottable geotextiles play an important part. Geotextiles with a flexible fibre composition shall be preferred to avoid the constraint of growing roots. The rooting can efficiently support the filter function of a geotextile (Schuppener 1993).

Coco, jute, ramie, hemp and flax can be chosen as natural raw materials but it has to be pointed out that for the processing of jute usually ecologically incompatible finishings have to be chosen.

A lot of applications require three-dimensional (i.e. thick) structures. Jute wovens or similar products used so far (like e.g. woven fabrics with synthetic warp fibres and natural ramie-weft fibres) cannot fulfil these requirements.

In May 1995 *Naue Fasertechnik* terminated the two-year research project "Development and testing of the applicability of flax fibres as geotextile nonwoven fabrics and composite materials for earth construction and hydraulic engineering" with a final report (Saathoff & Müller 1995).

It was the aim of this research project to produce mechanically bonded nonwoven fabrics and composite materials from flax fibres using the needle-punching and knitting technique and to examine the use of such products for geotextile application cases in earth construction and hydraulic engineering. It was planned to modify prototypes in several steps by using appropriate production techniques so that the characteristic values of synthetic geotextiles (called "models") were fulfilled either to the largest degree or even completely. Select results are summarised in the following:

2 FLAX FIBRES

Fibre raw material can be divided into

- synthetic fibres made from natural polymers (e.g. the man-made cellulose fibre viscose) and synthetic polymers (e.g. polyolefines PE and PP) as well as from inorganic substances (e.g. glass or ceramics) and
- natural fibres consisting of mineral fibres (e.g. asbestos) and animal fibres (e.g. sheep's wool) as well as of vegetable fibres with the main groups seed fibres (e.g. cotton), hard fibres (e.g. sisal or coco) and bast fibres.

Besides hemp, jute, ramie and others flax belongs to the group of vegetable bast fibres and, being part of the family of flax plants, to the oldest cultivated plants. Already in the Stone Age flax was used for the manufacturing of clothing.

For textile production flax is mainly harvested by weeding. The harvested stalk has to be opened so that the wooden parts can be separated from the fibre parts more easily. This procedure produces shives as well as tow. The so obtained flax, the most valuable fibre part, is further refined by hackling and after that processed to fine, high-quality flax yarns by using the wet spinning method.

In cooperation with the *Sächsisches Textilforschungsinstitut e. V. Chemnitz,* acting as R/D subcontractor, the initial material was first of all examined in detail. With respect to the selected short flax fibre types TR C1 and D4 C1 of the *Füssener Faser AG* as well as for Sachsenflachs F1 the following data can be summed up:

- The fibre fineness ranges between 16 and 19 dtex.

- The fibre length of approx. 25 to 35 mm lies beneath the range of 50 mm desired for the processing.
- The fibre strength (according to Presley preparation) ranges between 36 and 48 cN/tex.

3 EFFECTS OF SPIN FINISHINGS

The characteristic even structure of flax fibres leads to an insufficient fibre composition and to an extremely high friction to metal surfaces during the production process. Consequences are irregularities in the nonwoven fabric structure, high loads to working elements and increase of the noise level in the operating area of processing machines. The fibre preparation with spin finishings is a possibility to improve the workability of flax fibres.

Biologically degradable, adhesive spin finishings of different manufacturers and different chemical composition were examined. The suggestibility of the adhesion between the fibres (friction fibre-fibre) in longitudinal direction was established by determining the maximum tensile strength of the unbonded fibre before needle-punching. Forces occurring during the reorientation of the fibres during the needle-punching process (friction metal-fibre) were determined by placing wire strain gauges under the needle puncture plate.

The test results can be summarized as follows:

- In general short flax fibre types offer a considerably lower fibre composition than e.g. viscose fibres. The friction fibre-fibre can be increased by up to 45 % using suitable spin finishings, in individual cases the friction fibre-fibre may as well be reduced (Fig. 1).
- The friction fibre-metal can be reduced by up to 32 % using suitable spin finishings, in individual cases the friction fibre-metal may as well be increased (Fig. 2).

It was the aim of these tests to improve the fibre consistency and to simultaneously reduce the friction fibre-metal. As the spin finishings are mainly aimed at the improvement of one of the two parameters, the spin finishings have to be chosen according to priority.

Low and one-sided effects respectively were achieved with spin finishings causing a high residual fat content on the fibre and high concentrations on the flax fibre or leading to a hydrolysis on the flax fibres. Spin finishings, the components of which cannot be found on the flax fibre or which intensify the natural lipids of the flax provided the best efficiency regarding the increase in the friction fibre-fibre and the reduction of the friction fibre-metal.

4 CHARACTERISTIC VALUES OF NEEDLE-PUNCHED PROTOTYPES

Initial tests aimed at the adjustment of the machine parameters to the flax raw material. In further tests on the processability of the short flax fibres (1500 needles/running meter, 600 strokes/min) with a desired mass per unit area of 300 g/m^2 the fabric was partially destroyed. The following completion of two corresponding liners revealed an average mass per unit area of only 450 g/m^2.

The processing behaviour (dust formation, inflammability) with the influence of the flax fibre and spin finishing material on the nonwoven formation and bonding was improved in the following tests. Numerous mechanical modifications were required and carried out to achieve this improvement. The following examples can be quoted:

- Encapsulation of the fibre preparation plant, construction of a suitable spin finishing device, development and manufacturing of an exhaust in the area of the card feeding system etc.

In the following tests production parameters, machine adjustments as well as the auxiliary means of production were optimised. The following examples can be quoted:

- Continuous variation of the use and the arrangement of felting needles, variation of the number of strokes and the thrust, increase of the spin finishing share, improvement of the spin finishing application etc.

Concerning the variation of the felting needles the following can be pointed out:

- The coarse needles used in the pre-needle machine (15 • 18 • 25 • 3.5 Regular Barb 333) were replaced by finer needle types (15 • 18 • 30 • 3.5 Regular Barb 333). Further modifications were carried out in the working area of the needles by varying the projecting length of the groove (kick-up).
- In the finish-needle machine considerably finer needles (15 • 18 • 36 • 3.0 Close Barb 333) were used. These needle types immediately proved their efficiency.
- The coating of the needles for the flax processing with chromium or similar materials would be advantageous due to the low wearing.

After first tests concerning the processability of the short flax fibre were carried out, where a mass per unit area of 300 g/m^2 and the destruction of the fabric structure were desired, the mass per unit area was varied between approx. 200 and 1150 g/m^2. In Table 1 select results are presented.

Although a relatively high strength of the individual fibre was determined the strength could not be transferred to the mechanically bonded nonwoven fabric. The reasons are damaging of the flax fibres, irregularities of the fibre structure and a considerable variation of the fineness ratios (dtex/fibre length).

In tests with needle-punched flax fibre nonwoven fabrics the plunger puncture force of Secutex® 351-4 (2500 N) could not be achieved although the mass per unit area was varied. Even composite materials incorporating flax woven fabrics (among others test R 13) achieve maximum plunger-puncture forces of only 1947 N. Only needle-punched products with fibre mixtures of polypropylene and

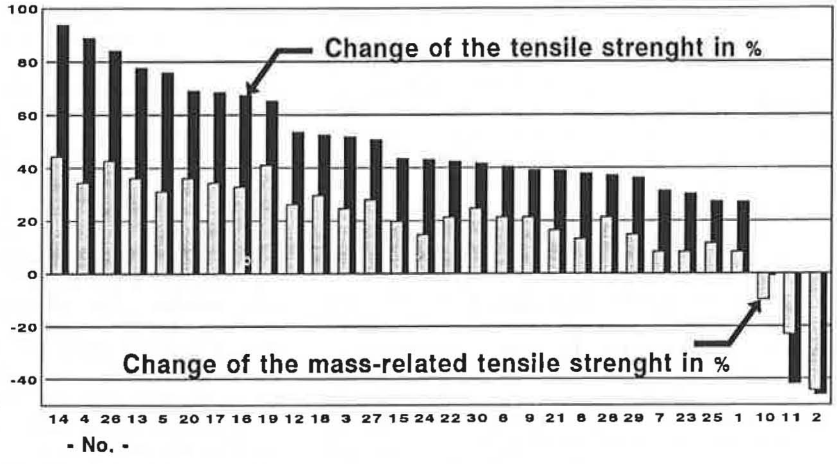

Fig. 1. Spin finishing treatment of flax fibres, modification of the fibre-fibre friction

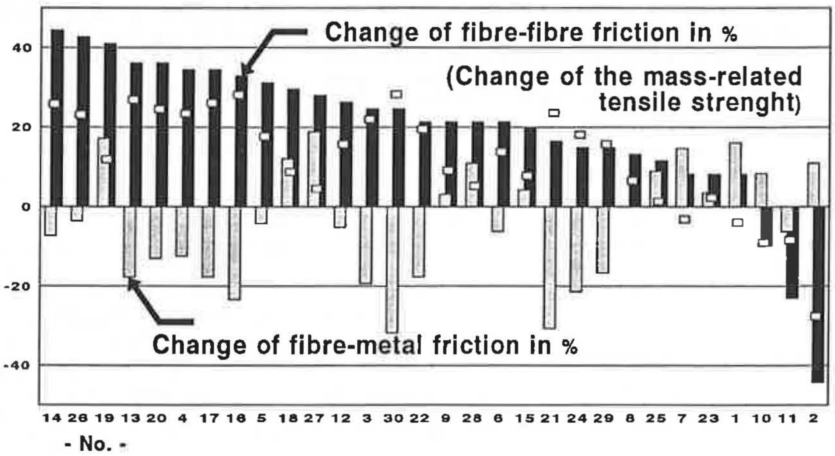

Fig. 2. Spin finishing treatment of flax fibres, modification of the reorientation force (fibre-metal friction)

Table 1. Laboratory results of needle-punched flax fibre nonwoven fabrics

1) with a flax woven fabric

test / measuring results	R 2	R 4	R 6	R 13	R 18	R 22	R 24	S 351	T 600
flax fibre share [%]	100	100	100	100	100	50	50	0	0
fibre addition [%]				1)	1)	50 PP	50 PP	-	-
mass per unit area [g/m²]	325	550	732	1012	581	538	515	325	603
thickness [mm]	2.7	3.4	3.9	4.7	2.8	5.3	5.1	3.2	4.8
tensile strength longit. [N/10cm]	111	218	505	1897	1682	1600	1306	1350	1452
elongation longit. [%]	57	51	43	14	14	95	87	75	96
tensile strength cross [N/10cm]	87	196	361	1746	1674	2228	1714	1980	3106
elongation cross [%]	77	65	72	6	5	100	94	56	56
plunger-puncture force [N]	160	358	670	1947	1621	2749	2375	2520	-
deformation [%]	58	45	46	8	8	89	84	70	-
$O_{90,W}$ [mm]	0.08	0.08	0.08	0.06	0.08	0.08	0.09	0.09	0.08
k_V BAW [m/s]	$2.6\ 10^{-4}$	-	$1.9\ 10^{-4}$	$8.5\ 10^{-5}$	$1.4\ 10^{-4}$	$3.7\ 10^{-4}$	-	-	$1.6\ 10^{-3}$
$k_{V.2}$ F-I [m/s]	$3.1\ 10^{-4}$	$3.1\ 10^{-4}$	$2.7\ 10^{-4}$	$5.7\ 10^{-5}$	$9.3\ 10^{-5}$	$1.9\ 10^{-4}$	-	$4.8\ 10^{-3}$	-
$k_{V.20}$ F-I [m/s]	$1.0\ 10^{-4}$	$5.4\ 10^{-6}$	$8.3\ 10^{-5}$	$3.0\ 10^{-5}$	$5.2\ 10^{-5}$	$1.3\ 10^{-4}$	-	$2.3\ 10^{-3}$	-
$k_{V.200}$ F-I [m/s]	$1.7\ 10^{-6}$	-	-	$2.3\ 10^{-6}$	$4.4\ 10^{-6}$	$2.5\ 10^{-5}$	-	$6.9\ 10^{-4}$	-

flax (e.g. test R 22) exceed the required plunger-puncture force.

The tensile strengths in machine direction of needle-punched flax fibre nonwoven fabrics are generally higher than in cross direction. This behaviour is usually opposite for customary needle-punched nonwoven fabrics made from cut staple fibres. None of the needle-punched pure flax fibre nonwoven fabrics reaches the value of 1200 N/10 cm in the tests. Only composite materials incorporating flax fibre woven fabrics (e.g. R 13 and R 18) and needle-punched products with fibre mixtures of polypropylene and flax (e.g. tests R 22 and R 24) exceed the tensile strength in machine and cross direction required for hydraulic engineering in Germany.

The main aim of these tests was to determine the influence of PP-additions on the strength behaviour of the whole product by maintainig the mass per unit area. Concerning the pure strength behaviour a PP addition of 50 % proved, as expected, to be disadvantageous. Compared to 100 % PP-products with the same mass per unit area the mechanical characteristic values deteriorated. Compared to pure flax fibre nonwovens the mechanical characteristic values were considerably improved.

Concerning the other characteristic values of needle-punched nonwovens the following can be stated:

- As expected, fixed marginal conditions during production result in an effective opening size $O_{90,w}$ of approx. 0.08 mm in all tests.
  An additionally examined, coarse and therefore less dissolved tow fibre caused the doubling of the effective opening size of these products compared to other flax fibre nonwoven fabrics.
- The water permeability in vertical direction to the product plane k_v is -due to the high water absorption capacity of the flax fibres and the entailed "swelling"- up to two decimal powers lower than desired. In case of low loads -which may be the normal case- a reduction of k_v ($k_{v,\ BAW}$ and $k_{v,2,\ F\text{-}I}$ respectively) of approx. a half decimal power has to be expected.
- The water permeability in the product plane k_h is higher than the water permeability vertical to the product plane k_v and for small loads it usually ranges around $3 \bullet 10^{-3}$ m/s.
- The requirements to the combustion behaviour could mostly be fulfilled in the course of the project by changing the production parameters. It may be assumed that flax fibre nonwovens with $m_A \geq 500$ g/m^2 always fulfil combustion class B2.
- The soil retaining capacity of needle-punched flax fibre nonwoven fabrics towards soil type BT 2, BT 3 and partially even soil type BT 4 -tested according to the BAW method- is mainly fulfilled.

Further tests revealed that the test results are not influenced by using different flax fibre types of the same quality (TR C1, D4 C1 and Sachsenflachs F1) The better the flax fibre is dissolved and cleaned (flax quality) the better the processability. With a 50 % portion of flax tow the wooden parts in the material did not disturb the processing even with respect to the formation of dust. Especially from an economic point of view the use of flax tow is of interest as its price is considerably lower than that of synthetic and short flax fibre types.

The strength behaviour has a central significance for the production of prototypes. The requirements concerning the strength of the flax fibre nonwoven fabrics can -as per the a.m. explanations- not be achieved only with the needle punching technique. Additionally chosen production techniques like *Malivlies* and *Kunit* are according to the results not very suitable. The characteristic values of the synthetic "models" Secutex® 351-4 and Terrafix® 600 -in Tables 1 and 2 abbreviated with S 351 and T 600- can only be achieved if a high mass per unit area of the flax fibre (possibly with a PP addition of 50 to 70 %) or composite materials with incorporating flax woven fabrics are used. Other technologies have to be used to achieve the mechanical characteristic values of synthetic nonwoven fabrics in a cost saving way. In the following paragraph the results with *Maliwatt*-bonded nonwoven fabrics are explained.

5 CHARACTERISTIC VALUES OF MALIWATT- BONDED PROTOTYPES

A further main point to achieve the high tensile strength and plunger-puncture force of the models was the *Maliwatt*-bonding (Grenzendörfer 1993). In cooperation with *Karl Mayer Malimo Maschinenbau GmbH Chemnitz* multilayer needle-punched flax fibre nonwoven fabrics were knitted to compact materials by using the *Maliwatt*-technique.

Furthermore bond type, sewing thread and machine adjustments were varied. The tricot bonding was considered as being the optimum solution. Flax yarn, flax thread, polyester silk, viscose silk in single and double design and viscose cord type of different thicknesses were tested as sewing threads. The machine refinement was chosen with F 3.5 and a stitch length of between 2.5 and 3.5 mm.

As mentioned, tensile strengths of at least 1200 N/10 cm in machine and cross direction are required for hydraulic engineering ("model" Terrafix® 600). This is in longitudinal direction usually achieved for the *Maliwatt*-bonded nonwoven flax fibre fabrics. The tensile strength in cross direction can be achieved with a mass per unit area of approx. $m_A = 1000$ g/m^2 (e.g. test 93.93 in Table 2).

During the tests with *Maliwatt*-bonded flax fibre nonwoven fabrics made from two layers of needle-punched flax fibre nonwoven fabrics a plunger-puncture force of > 2500 N can be achieved with a mass per unit area of approx. $m_A = 1000$ g/m^2 (e.g. test 93.93 or 94.09). Single thread viscose silk (or viscose cord type) with a fibre fineness of 122 tex should be used as sewing thread.

To further improve the plunger-puncture forces and tensile strengths for *Maliwatt*-bonded flax fibre

Table 2. Laboratory results of *Maliwatt*-bonded flax fibre nonwoven fabrics

1) untwisted

measuring results / test	93.13	93.15	93.19	93.27	93.93	93.94	94.09	S 351	T 600
flax fibre share [%]	100	100	100	100	100	100	100	0	0
mass per unit area [g/m²]	1751	1810	2044	861	956	1103	986	325	603
thickness [mm]	8.5	9.1	6.9	4.3	5.0	4.9	4.8	3.2	4.8
m.p.a. prenonwoven [g/m²]	436	436	732	732	-	-	-	-	-
number of prenonwoven layers	4	4	3	1	2	2	2	-	-
bonding of layers	Tricot	Tricot	Tricot	Tricot	Tricot	Tricot	Tricot	-	-
raw mat. of sewing threads	N.N.	PES-S	PES-S	PES-S	CV-S	CV-S (2x)	CV-S	-	-
thickness of sewing threads [tex]	N.N.	47.6	167	47.6	122	122	122	-	-
machine fineness	F 3.5	F 3.5	F 3.5	F 3.5	F 3.5	F 3.5	F 3.5	-	-
stitch length [mm]	3.5	3.5	3.5	3.5	3.5	3.5	2.5	-	-
tensile strength longit. [N/10cm]	1674	1780	4090	1883	1904	2600	1806	1350	1452
elongation longit. [%]	42	48	40	49	54	49	46	75	96
tensile strength cross [N/10cm]	1253	1228	2470	835	1386	1656	203 1)	1980	3106
elongation cross [%]	66	62	64	87	103	95	29	56	56
plunger puncture force [N]	-	-	-	-	2837	4080	2737	2520	-
deformation [%]	-	-	-	-	47	46	28	70	-
$O_{90,W}$ [mm]	-	-	-	0.07	0.07	0.06	0.05	0.09	0.08
k_V BAW [m/s]	-	-	-	$4.0 \cdot 10^{-5}$	$2.8 \cdot 10^{-5}$	$3.2 \cdot 10^{-5}$	-	-	$1.6 \cdot 10^{-3}$
$k_{V,2}$ F-I [m/s]	-	-	-	$1.2 \cdot 10^{-4}$	$2.0 \cdot 10^{-4}$	$1.7 \cdot 10^{-4}$	-	$4.8 \cdot 10^{-3}$	-
$k_{V,20}$ F-I [m/s]	-	-	-	$3.9 \cdot 10^{-5}$	$4.1 \cdot 10^{-5}$	$4.5 \cdot 10^{-5}$	-	$2.3 \cdot 10^{-3}$	-
$k_{V,200}$ F-I [m/s]	-	-	-	$2.1 \cdot 10^{-6}$	$1.8 \cdot 10^{-5}$	$2.6 \cdot 10^{-6}$	-	$6.9 \cdot 10^{-4}$	-

nonwoven fabrics processing the same mass per unit area it may be possible to use needle-punched nonwoven fabrics made from flax/PP mixtures or a combination of a needle-punched flax fibre fabric with a linen woven fabric.

Concerning the other characteristic values of *Maliwatt*-bonded flax fibre nonwoven fabrics the following can be stated:

- The elongations/deformations are relatively low.
- The effective opening size ranges around 0.07 mm.
- The *Maliwatt*-bonding results in a further reduction of the water permeability compared to the needle-punched prototypes.
- The requirements to the combustion behaviour were fulfilled.
- The soil retaining capacity is -compared to the needle-punched prototypes- usually further improved.

6 ADDITIONAL TESTS

Additional tests were carried out concerning the abrasion, shear and degradation behaviour.

Pure flax fibre nonwoven fabrics, even those with a mass per unit area of 1000 g/m², which are produced according to the *Maliwatt*-technique do not fulfil the abrasion test. Products made from 50 % flax and 50 % PP with a mass per unit area of 544 g/m² pass the test. PP-additions have to be recommended to achieve the required abrasion resistance.

The results of the shear tests prove the possible use of geotextiles made from flax fibres in slopes (angle of friction against sand in the range of 30°).

In cooperation with the *Sächsisches Textilforschungsinstitut e.V. Chemnitz* (Fuchs & Schmalz 1994) the degradation behaviour towards micro-organisms and in the Global UV-test and the Suntest (Schmalz, Lembicki & Saathoff 1994) was examined.

- When evaluating the tests concerning the degradation behaviour towards micro-organisms it has to be stated that flax fibre nonwoven fabrics which are completely surrounded by earth very quickly sustain a clear decrease of strength due to the influence of micro-organisms and wetness. This rapid degradation would question several fields of application (e.g. during rooting of plants at a slope). The rapidness of the degradation, however, was not expected. Since these results were only achieved in laboratory tests and since they cannot generally be transferred to natural conditions, a test field seems to be recommendable.
- After the Global UV test pure flax fibre nonwoven fabrics showed a clear increase of the tensile strength.
- The tests concerning the degradation behaviour in the Suntest revealed that flax fibre nonwoven fabrics bleach out and even after two cycles show

a higher tensile strength compared to the initial tensile strength. In this case the fibre fineness is of considerable importance. The increase in strength with a simultaneous reduction of the fibre fineness can be explained by a kind of interlacing.

- Regarding the resistance against micro-organisms of nonwoven fabrics made from flax and PP, the PP fibres are responsible for the UV resistance and the flax fibres are responsible for the remaining tensile strength. The mixture ratio flax/PP is decisive for the resistance against Xenon-radiation. The mixture ratio 50 % flax and 50 % PP has in all cases an advantageous influence on the resistance.
- The application of special finishings (e.g. spin finishings with stabilizers) may be suitable to improve the degradation behaviour of flax fibre nonwoven fabrics.

7 CONCLUSIONS

The strength behaviour plays an important part in the development and production of flax-geotextiles. With an increasing mass per unit area all prototypes tend to show a higher tensile strength and plunger-puncture force. Different kinds of flax fibre winning and processing, the resulting fibre fineness, use, raw material and thickness of possible sewing threads, machine fineness and stitch lengths, use of spin finishings and synthetic additions etc. make it difficult to estimate the characteristic values. It may be summarized, however, that within the scope of this research project extensive trend-setting tests were carried out.

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The authors are responsible for the content of this paper.

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