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Development of Sustainable Yarns from an Innovative Combination of European Hemp and Pure Recycled Wool

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ABSTRACT

Currently, only a very small percentage of textiles is recycled; the majority is incinerated or sent to landfill. Due to the advancing climate change, the responsible use of available resources is becoming more important than ever. The process of rethinking begins in product development with the selection of raw materials. In the project "CannaReWool" (EFRE-0802000), German hemp and pure recycled wool are blended, spun and knitted into fabrics. The aim of the project is to produce knitted fabrics that can be recycled in a closed loop due to their novel combination of materials. The aim is to determine the most suitable settings and spinning components to ensure a stable rotor spinning process. The evaluation is based on the number of yarn breaks per rotor hour. The trials are carried out on the Schlafhorst Autocoro 480 rotor spinning machine. As both fibers, hemp and recycled wool, are very short and lack fiber to fiber cohesion, it becomes apparent that no settings can be found that give the spinning process sufficient stability. The results of the Uster Tester 6 and the Textechno Statimat tests show that the yarns contain a high amount of imperfections and the tensile strength values are low. Nonetheless the yarn is successfully knitted into fabrics on a Stoll ADF flat knitting machine. In the course of the project, the knitting trials will be continued and areas of application for the fabrics will be determined.

1 Introduction

In Germany, approx. 392,000 t of textile waste are generated annually, which is about 4.7 kg per capita. In addition, almost 1.3 million t of used textiles are collected every year via used clothing collection points. In 2015, 62% of the textiles from the collections were reused in their original form, 14% were reused e.g. in the form of cleaning rags, 12% were materially recycled, 8% were thermally recovered and 4% were disposed of as waste [1,2].

Globally, the situation is different. Less than 1% of textiles are recycled into products of the same or similar quality, 12% are downcycled into products of lower value, such as insulation material or cleaning rags, and the majority of 73% are landfilled or incinerated. Over 97% of the raw materials used in the textile industry are virgin feedstock and only 2% materials are generated from recycling processes [3].

In addition to the environmental damage caused by sending textile waste to landfill, the textile lifecycle also produces greenhouse gases. A World Economic Forum report states that 2% of greenhouse gas emissions caused by the fashion industry can be reduced through recycling processes. Another 10% depend on agricultural factors from raw material cultivation and can be reduced, for example, through organic farming [4].

A look at the conditions under which cotton is grown shows that it is associated with major environmental impacts. At about 25%, it holds the second largest share of fiber production worldwide and is the world's most used natural fiber. Cotton requires large amounts of water, mineral fertilizers and pesticides in cultivation. In 2014, 16% of insecticides sold and 4% of herbicides sold were intended for cotton cultivation. The pesticides are applied several times a year in conventional cotton cultivation and thus enter the water cycle [3,5,6].

From an ecological point of view, hemp offers an alternative to cotton. It is fast-growing and naturally resistant to pests, fungi and weeds, making it well suited for organic cultivation. Above all, the low water consumption is shown in direct comparison to cotton: Cotton requires between 9,800 l and 10,000 l of water per kg of fiber during cultivation, whereas hemp only requires about 2,000 l to 3,400 l of water per kg of useful fibers. Breaking down the fibers within this useful matter also takes up water. An additional amount of around 80 l per kilo is needed. Usually, the water requirement for hemp cultivation can be covered by rainfall [7,8].

Hemp can be grown in most climatic zones. In Germany, 6,444 ha of land were cultivated with hemp plants in 2021, China is ahead with estimated 66,700 ha in 2019 [7,9,10].

In order to use the hemp fibers, they have to be processed as blends. Recycled fibers offer great potential for this, as almost three quarters of textile waste worldwide are still incinerated or landfilled. To be able to produce a product that is closed loop recyclable and additionally has a low impact on the environment, the blend should be biodegradable. Moreover, supply chains should be as local as possible [3].

A fiber that is biologically degradable and available as recycled pure material is wool. Therefore, in the trials described below, hemp grown in Germany and pure recycled wool are combined. The aim of the trials is to determine settings and spinning components that make it possible to spin this novel fiber combination into a yarn in a stable rotor spinning process.

2 Trial setup

Two types of hemp are procured. The first type (Hemp 1) is winter hemp grown in Germany (Fig. 1a). Winter hemp is an intercrop that is left in the field over winter, which replaces the traditional retting process. This type of hemp is known for its fine fibers [11]. For this trial it is available bleached but not cottonized. The second type (Hemp 2) was cultivated in France, Belgium and the Netherlands and is unbleached and cottonized (Fig. 1b). The recycled wool is sourced from a textile recycling company. The fibers originate from pre-consumer carpets that have been shredded into shoddy wool (Fig. 1c). The material is available on the market in large quantities.

(a) (b) (c)

Fig. 1: (a) Hemp 1, German hemp, bleached, not cottonized; (b) Hemp 2, hemp from France, Belgium, Netherlands, unbleached, cottonized; (c) recycled wool from pre-consumer carpets.

The first step is to cottonize the bleached German hemp (Hemp 1). Cottonization is a process to modify flax and hemp in order to make the fibers resemble cotton fibers. It is done by splitting complex hemp fibers up which creates finer fibers [12-14]. In Test 1.1 the material passes through the universal bale opener BO-U, the universal fine cleaner CL-C3 and the carding machine TC 15 S (Hemp 1.1). Since the hemp is already strongly dissolved and also shortened by the carding machine, it is removed from the process earlier in a second test, after passing through the fine cleaner CL-C3 (Hemp 1.2).

Table 1 shows that the test results of Hemp 1.1 and Hemp 2 lie in a similar range. Hemp 2 is slightly coarser with a micronaire of 8.4, the short fiber content of 8% and the mean fiber length of 27.5 mm can be considered the same. The shredded wool has the shortest fibers with 21.8 mm and the largest short fiber content with approx. 29%.

Table 1: Fiber test results from Textechno CCS

	Hemp 1	**Hemp 1.1**	**Hemp 1.2**	**Hemp 2**	**Recycled Wool**
Fiber Fineness	Mic. 13.88	Mic. 7.98	Mic. 12.33	Mic. 8.38	42.64 µm
Short fiber content (%)	0.85	8.17	1.13	8.10	29.09
Mean length (mm)	66.64	27.30	61.00	27.49	21.79

For the blending the materials are prepared separately. The shredded wool is fed into a universal cleaner CL-C3 via a universal bale opener BO-U and then deposited by a weigh feeder BL-HF. The hemp is opened using a universal bale opener BL-BO with an integrated weighing box feeder and deposited on the wool as the second layer. The fibers then pass through a mixing opener BL-TO universal mixer MX-U6, dosing opener FD-S and finally the carding machine TC 19 S. The integrated draw frame module IDF 2 gives the sliver a draft of 1.4 directly before coiling it into cans.

As shown in Table 2, four blends are produced. Blend 1.1 consists of 50% bleached German hemp cottonized by using the fine cleaner and the card (Hemp 1.1) and 50% recycled wool. Blend 1.2 consists of 50% bleached German hemp cottonized only with the fine cleaner (Hemp 1.2) and 50% recycled wool. The unbleached hemp from France, Belgium and the Netherlands (Hemp 2) is processed in two blend ratios. As Blend 2.1, 50% hemp / 50% recycled wool and Blend 2.2., 25% hemp / 75% recycled wool.

Table 2: The composition of the four hemp wool blends

Blend 1.1	Blend 1.2	Blend 2.1	Blend 2.2
50% Hemp 1.1	50% Hemp 1.2	50% Hemp 2	25% Hemp 2
50% recycled wool	50% recycled wool	50% recycled wool	75% recycled wool

The spinning trials are carried out on the Schlafhorst Autocoro 480 rotor spinning machine at Niederrhein University of Applied Sciences. The aim of the trials is to identify the settings and spinning components with which the production of the finest possible yarn can be achieved in the most stable spinning process.

Initially, a screening test is carried out to get an overview of the influence of the spinning components and settings. The basis for this is the Schlafhorst application recommendations for linen [15]. Material 2.1 is selected for the trials, as it shows the best running behavior during processing at Trützschler Group SE Textilmaschinenfabrik. The criteria by which the trials are evaluated are the yarn breaks per rotor hour. The best combination of spinning components and settings from the screening trials is used as a reference trial set-up (See Table 3, column 1 (Reference)). Based on these reference settings, all parameters relevant for spinning stability are tested individually and varied in different combinations. In addition, all four material blends produced at Trützschler Group SE Textilmaschinenfabrik are tested. A total of 26 trial set-ups are thus realized. In this article only the most promising set-ups are presented.

Table 1: Settings for the spinning trials on the Schlafhorst Autocoro 480 rotor spinning machine

	1 Reference	2	7	11	15	16	17	21	23
Rotor	TT-546BD	***U-546BD***	TT-546BD	TT-546BD	TT-546BD	TT-546BD	TT-546BD	TT-546BD	***U-546BD***
Rotor speed (rpm)	50’000	50’000	50’000	50’000	50’000	50’000	50’000	50’000	50’000
Opening roller	B20DN	B20DN	***S22P***	B20DN	B20DN	B20DN	B20DN	B20DN	B20DN
Opening roller speed (rpm)	7’000	7’000	7’000	7’000	7’000	7’000	7’000	7’000	7’000
Draw-off nozzle	K8R-A	K8R-A	K8R-A	K8R-A	K8R-A	K8R-A	K8R-A	K8R-A	K8R-A
Twists/m	525	525	525	***575***	525	525	525	***575***	***575***
Draft / calculated yarn count	39 / Nm 7	39 / Nm 7	39 / Nm 7	39 / Nm 7	39 / Nm 7	39 / Nm 7	39 / Nm 7	39 / Nm 7	39 / Nm 7
Negative pressure (mbar)	75	75	75	75	75	75	***60***	***60***	***60***
Material	Blend 2.1	Blend 2.1	Blend 2.1	Blend 2.1	***Blend 1.1***	Blend 2.1	Blend 2.1	Blend 2.1	Blend 2.1
Spin finish	no	no	no	no	no	***yes***	no	no	no

To evaluate the process stability, the spinning time until yarn break is measured. At least 12 measurements are recorded per trial set-up. The measured times are then converted into yarn breaks per rotor hour.

As there is no standardized climate in the spinning laboratory and air humidity and temperature fluctuate, the reference set-up 1 is tested first on each trial day in order to be able to map the influence of the climate. As the trials show that the hemp can be processed better wet than dry, the slivers are sprayed with water for one second every 5 minutes.

3 Results

Figure 2 shows the number of yarn breaks per rotor hour. This is done by summing up all the measured times, dividing the number of measurements, which equals the number of yarn breaks, by the sum and then multiplying by 60. The reference trial is compared to the comparison trial with modified parameters of the same day. The diagram shows all comparison trials that achieved fewer yarn breaks per rotor hour than the reference trial of the same day or fewer yarn breaks per rotor hour than the mean value of all reference trials. In total, this applies to 5 different trial set-ups; 2, 7, 11, 16 and 17. It is remarkable that both the highest value, 12, and the lowest value, 5, are achieved with the reference trial set-up. The settings and spinning components of the trial set-ups 2, 7, 11, 16 and 17 can be seen in Table 3. The deviations from reference 1 are highlighted in bold and italic.

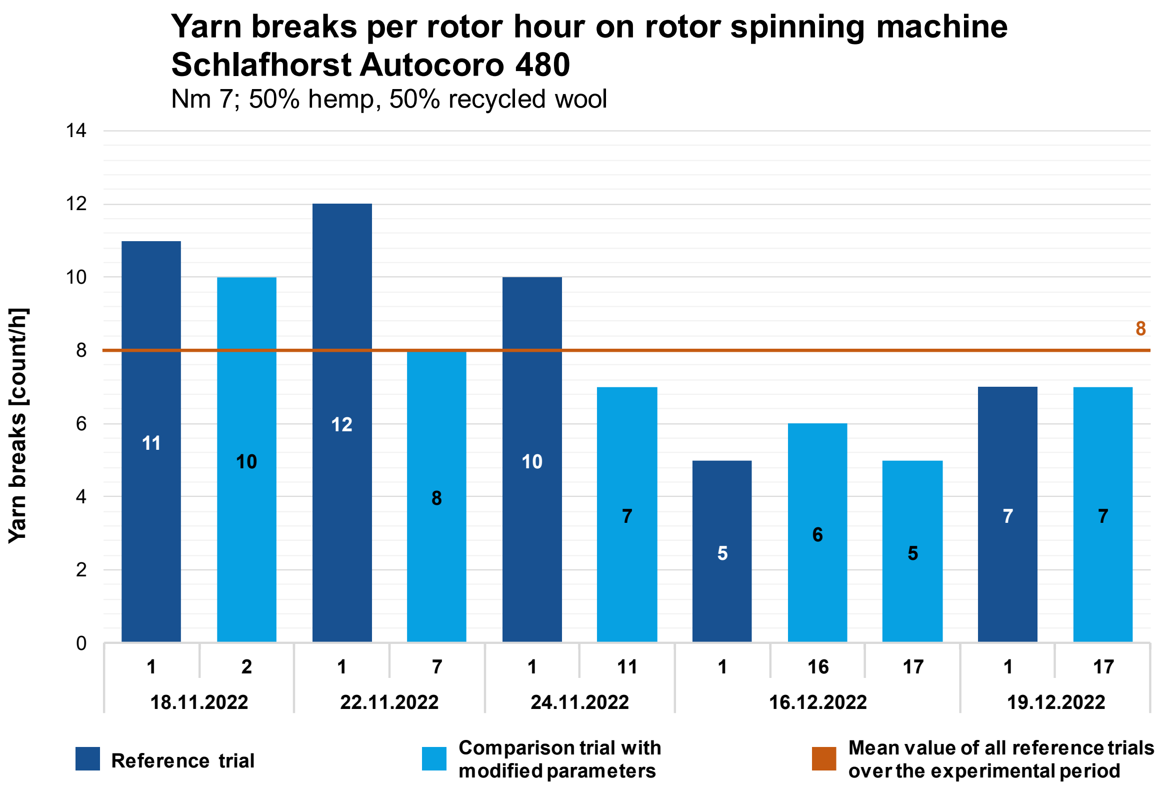

Figure 2: Yarn breaks per rotor hour compared to reference trial no. 1 of the respective day.

In the following trials, the settings and spinning components of No. 2, 11 and 17 are combined. The aim is to find out whether the properties with a positive influence on spinning stability lead to better results in combination. Opening roller S 22 P (No. 7) is omitted because the rough surface causes material to accumulate in the teeth, which can only be removed with difficulty. Also, the spin finish (No. 16) is not considered, as it causes increased fiber and dust build-up in and around the spinning box. The combination of the increased number of twists/m and the lower negative pressure is tested first with the rotor TT-546BD, as trial set-up 21, and second with the rotor U-546BD, as trial set-up 23 (Table 3).

In Fig. 3 the yarn breaks per rotor hour in trial set-up 1 are compared to the combinations 21 and 23. The reference set-up achieves 5 yarn breaks per rotor hour, set-up 21 achieves 14 yarn breaks and set-up 23 achieves 37 yarn breaks. The results of both combinations are higher than the reference set-up, which suggests that the reference set-up provides better spinning stability than set-up 21 and 23. The number of yarn breaks of set-up 21 and 23 is higher than the numbers of set-ups 2, 11 and 17, in which the settings are tested individually. This suggests that the combination of beneficial settings and spinning components does not necessarily lead to better spinning stability. As the trials were carried out on five different days, it is difficult to compare them due to the fluctuating climate.

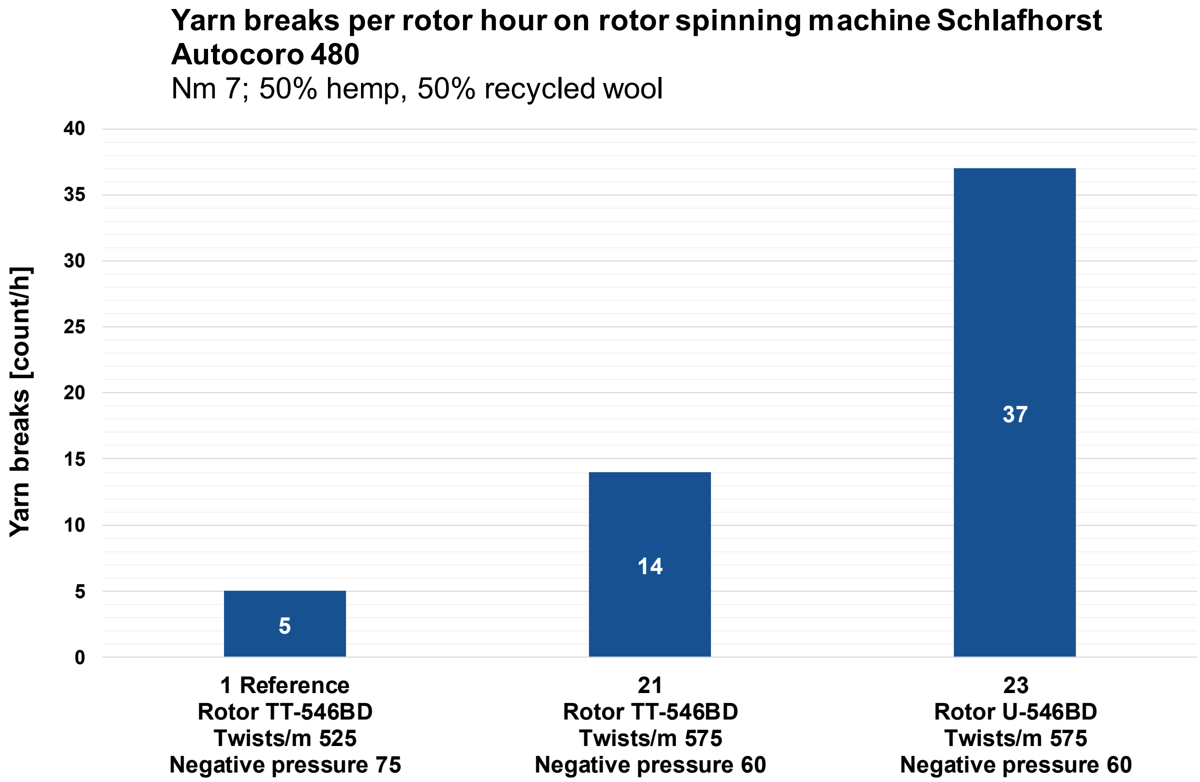

Figure 3: Yarn breaks per rotor hour of trial set-up 21 and 23 compared to reference trial no. 1 of the same day.

The yarns spun from set-up 1, 2, 7, 11, 16 and 17 are tested using the Uster Tester 6 and the Textechno Statimat. Trial set-up 15, which measures the influence of the material Blend 1.1, achieves an average of 12.54 yarn breaks per rotor hour. Since Blend 1.1 is a blend with German hemp, the yarn is considered in the yarn tests, although the number of yarn breaks lies above the reference of the same days and the average of all references.

Using the Uster Tester 6, 400 m of one bobbin of the yarn are tested. The yarn evenness value CVm is shown in Fig. 4 as a dark blue column, the mean value of all tests is represented by the lower red line. The yarn evenness value CVm lies between 18.8% and 19.7% for all set-ups, with a mean CVm value of 19.3%, which indicates a very uneven yarn. The lowest value is reached in trial set-up 16, the highest in set-up 17. The lower negative pressure of set-up 17 causes an increased accumulation of discarded fibers and trash at the discard point of the opening roller which are sometimes carried along with the incoming sliver and fed back into the process. This can lead to yarn breaks and can cause thick places and neps, but also fluctuations in the yarn mass.

The yarn count is shown in the diagram as a cyan rhombus; the mean value of all set-ups shown is represented by the upper red line. The yarn counts lie between Nm 7.17 and Nm 7.67, the two coarsest yarns are set-ups 2 and 16, while the finest one is spun from set-up 15, closely followed by the reference set-up with Nm 7.65. The mean yarn count is Nm 7.36. These variations may originate from the unevenness of the slivers, but as the slivers break during the testing process, it cannot be determined with certainty.

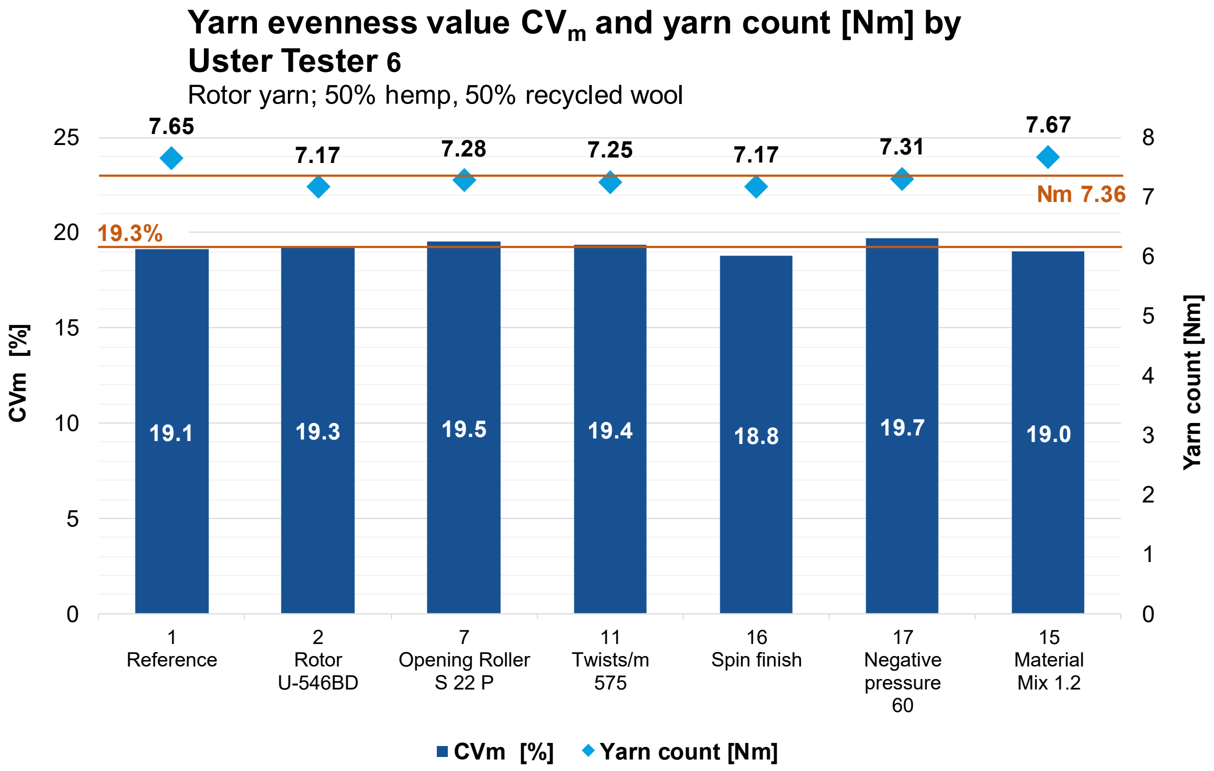

Figure 4: Yarn evenness CVm and yarn count according to Uster Tester 6.

In Fig. 5, the imperfections in the yarn are shown. The sums of the imperfections range from 610 to 873 imperfections per km. The lowest value is achieved with set-up 1, the reference; all modifications of these settings result in increased imperfection values. The highest amount of imperfections is achieved with set-up 17.

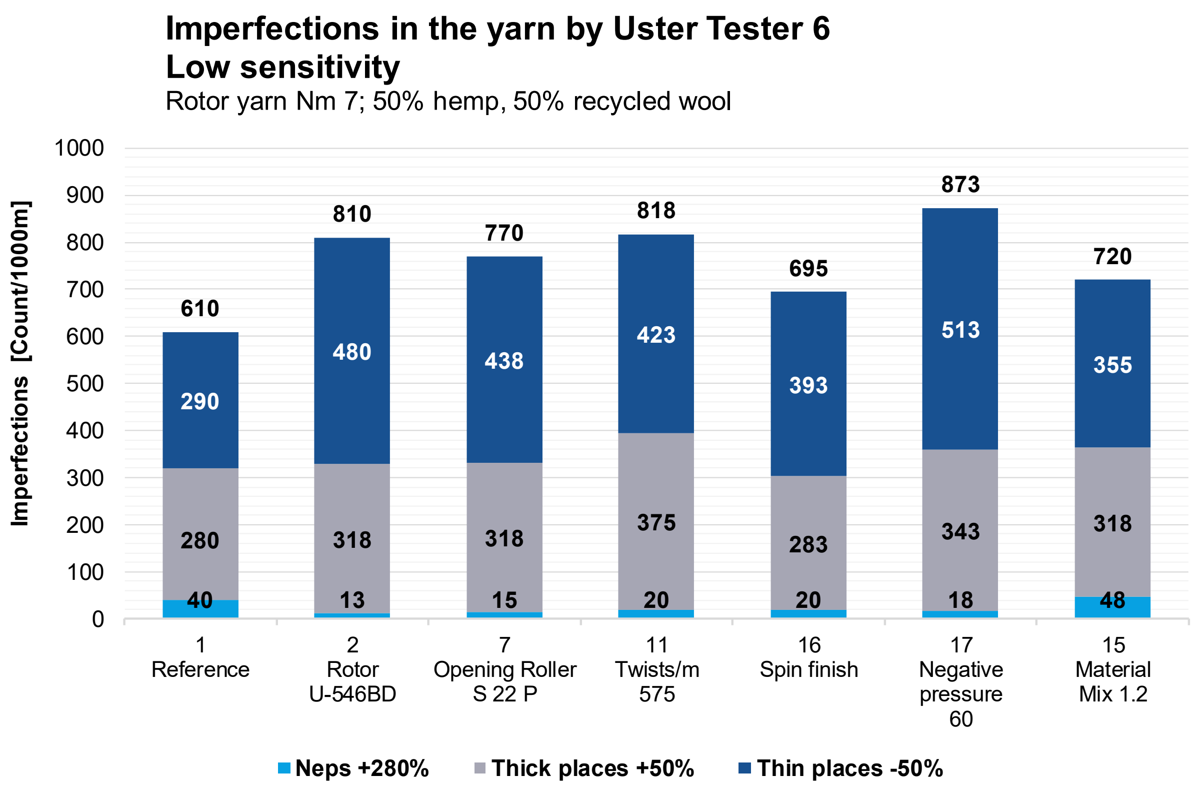

Figure 5: Imperfections in the yarn according to Uster Tester 6; low sensitivity.

The hairiness values of the yarns range from 11.99 to 13.44 and cannot be differentiated from each other with statistical certainty due to the small test range (Fig. 6). The lowest value is achieved with set-up 11, with an increased twist/m compared to the reference. This results in fiber ends being bound into the yarn rather than protruding from the yarn. Set-up 2 also lies above the reference, which may be due to the different rotor geometry. Rotor U-546BD has a wider rotor groove, in which the yarn is not compressed as much during twist insertion as in rotor TT-546BD from the reference. The highest value is reached in set-up 15 with the material Blend 1.1 which shows a hairiness of 13.44. This difference may be due to the material. Short and stiff fibers can lead to yarns with a higher hairiness [17,18]. In addition, the hemp in Blend 1.1 is bleached and can therefore behave differently than the unbleached hemp in the other trial set-ups. The mean value is 12.69%; it is marked in the diagram by the red line.

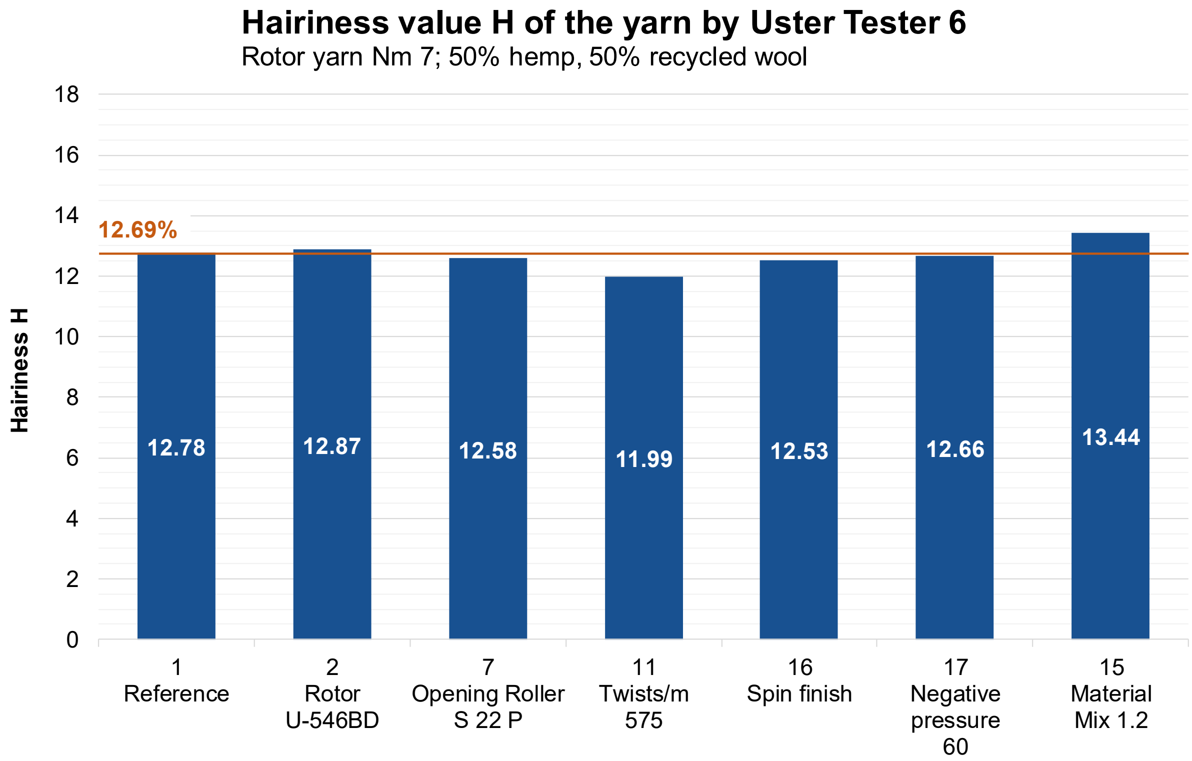

Figure 6: Hairiness H and standard deviation of hairiness H of the yarn according to Uster Tester.

The count-related tensile strength and elongation of the yarns is tested with the Textechno Statimat. 50 tears per bobbin are measured. In Fig. 7, the tensile strength values are shown in dark blue and the elongation values in cyan. The values for the count-related tensile strength range between 3.29 cN/tex and 3.68 cN/tex and cannot be distinguished from each other with statistical certainty due to the small scale of the test. The lowest count-related tensile strength is found in yarn No. 15, with 3.29 cN/tex, and the highest in yarn No. 16, with 3.68 cN/tex. The mean value is 3.51 cN/tex. The values for elongation range between 4.32% and 4.66% and can also not be distinguished from each other with statistical certainty due to the small scale of the test. The highest elongation value is achieved by trial set-up 1, the reference, with 4.66%, the lowest by number 15 with 4.32%. As a mean, the elongation is 4.41%.

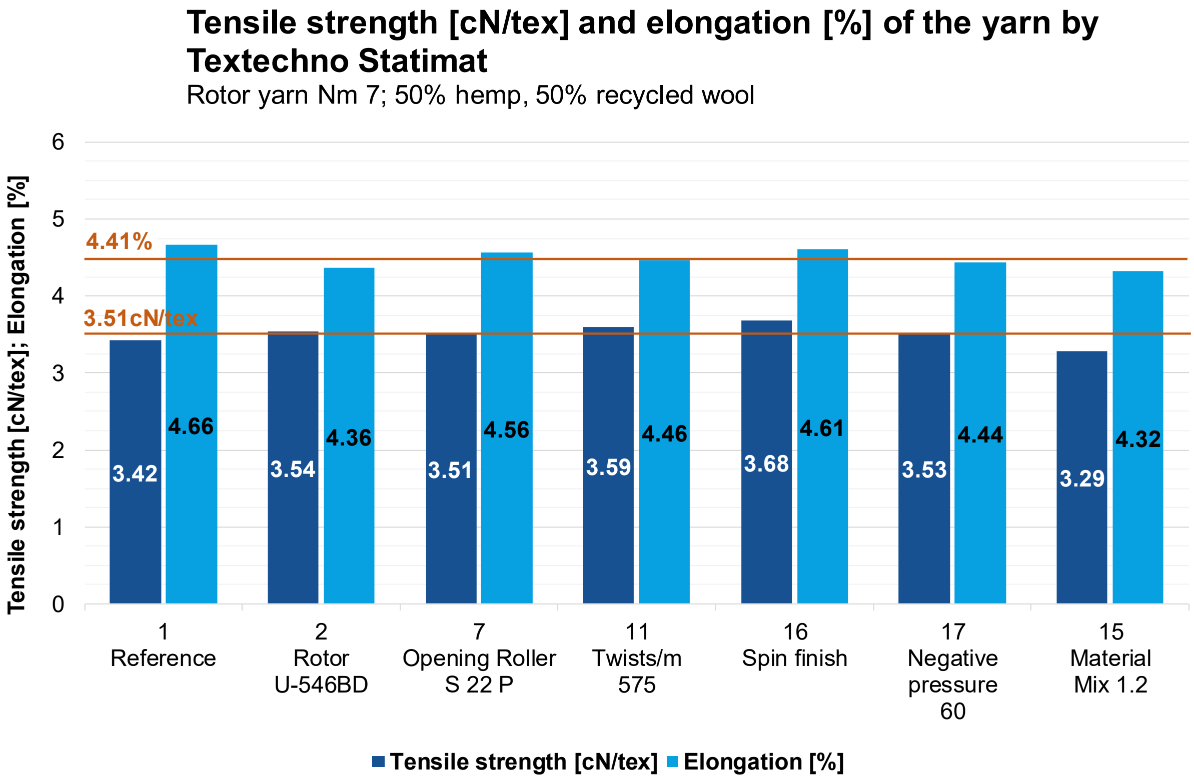

Figure 7: Tensile strength and elongation of the yarn according to Textechno Statimat.

In the next step, the reference yarn (Trial set-up 1) and the yarn with the bleached German hemp (Trial set-up 15) are steam treated at 132 °C for 5 minutes at 1.5 bar excess pressure in a Moers Spezialmaschinen GmbH autoclave and then paraffinized. The yarns are knitted on a Stoll ADF flat knitting machine with a gauge of 3,5.2 and woven on a Dornier EasyLeno weaving machine as wefts with a density from five to eleven wefts/cm.

4 Conclusion and Outlook

The variations between the reference trials are very high and it is not possible to say conclusively what causes the variations. In total, there are five set-ups in this trial series that achieve fewer yarn breaks per hour than the reference set-up 1: 2, 7, 11, 16 and 17. In order to verify that this situation is reproducible and not subject to the variations just mentioned, further trials must be carried out in which the set-ups are compared.

One reason for the high number of yarn breaks may be the high short fiber content of the recycled wool. This is supported by the fact that blend 2.2 with a higher wool content of 75% cannot be spun. Due to modern rotor spinning machines with individually driven spinning positions and individual piecing units, efficiencies of up to 99.6% can still be achieved with 1.4 yarn breaks per rotor hour [19]. This makes it possible to economically operate spinning processes that are less stable.

The project shows that it is possible to produce yarns from German hemp and recycled wool that can be knitted and woven. These findings can serve as a foundation for further research. A promising approach is to add longer carrier fibers to the hemp wool blend in order to increase the spinning stability and tensile strength of the yarn.

Author Contributions

Lisa Streitenberger: conceptualization, methodology, validation, formal analysis, investigation, data curation, resources, writing – original draft preparation, writing – review and editing, visualization, project administration; Prisca Holderied: conceptualization, methodology, validation, formal analysis, investigation, data curation, resources, writing – original draft preparation, writing – review and editing, visualization, project administration, funding acquisition; Julia Klausmann: conceptualization, methodology, validation, formal analysis, investigation, data curation, resources – review and editing – project administration; Thomas Mutschler: original draft preparation – review and editing, funding acquisition; Daniel Pattberg: methodology, validation, formal analysis, investigation, data curation; Thomas Weide: data curation, resources – original draft preparation – review and editing, supervision, project administration; Marcus O. Weber: conceptualization, methodology, validation, formal analysis, investigation, data curation, resources – original draft preparation – review and editing, supervision, project administration, funding acquisition.

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Conflicts of Interest

The authors declare no conflict of interest.

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