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***Araştırma Makalesi / Research Article***

# FRICTION COEFFICIENT MEASUREMENT OF HYBRID YARNS FROM BAST FIBRES – APPROACH OF A NEW TEST RIG

**Seyit HALAÇ***
**Alina RICHTER**
Institut für Textiltechnik, RWTH Aachen University, Germany

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***ABSTRACT*:** In this paper, research and studies on yarn spinning for textile fabric production have been investigated, including spinning of hybrid low-twist covered yarns made from natural and modified bast fibres. Friction values were analyzed before spinning to predict the yarn quality and processability of natural and modified bast fibres. Analyzing the friction values before spinning helps to predict the yarn quality and processability, enhancing the production efficiency. For this purpose, tribological tests were conducted on the Lünenschloss, a test rig newly developed by the ITA, including adhesion-slip tests on hemp-based slivers. This test rig uses stationary tensile force measurement to calculate the coefficient of friction of the tested fibre materials. The advantage of the Lünenschloss test rig is that it allows for testing with small quantities, providing reliable results even with minimal sample sizes, such as individual fibres or short yarn segments. Adhesion-slip tests were first carried out on various hemp-based slivers, including those containing polypropylene (PP). The results show that the sliver stability increased with the addition of PP fibres, which promises better stability in later processing steps. To confirm these results, friction coefficients were determined on the Lünenschloss test rig. These results correlated with the results of the adhesion-slip tests. Overall, these preliminary tests allow qualitative statements to be made about the reliable yarn production and resulting yarn stability. Based on these results, it can be assumed that promising yarns can be produced from modified fibres due to their properties.

***Keywords:*** hemp, fibres, friction value, yarn, Lünenschloss

# GÖVDE LİFLERİNDEN HİBRİT İPLİKLERİN SÜRTÜNME KATSAYISININ ÖLÇÜMÜ – YENİ BİR TEST STANDI KONSEPTİ

***ÖZ*:** Bu çalışmada, tekstil kumaş üretimi için yapılan iplik eğirme araştırmaları incelenmiş, doğal ve modifiye kenevir liflerinden yapılan hibrit düşük bükümlü iplikler de ele alınmıştır. İplik kalitesini ve işlenebilirliğini tahmin etmek amacıyla eğirme öncesinde sürtünme değerleri analiz edilmiştir. Sürtünme değerlerinin analiz edilmesi, iplik kalitesini ve ham maddenin işlenebilirliğini tahmin etmeye yardımcı olarak üretim verimliliğini artırmaktadır. ITA tarafından geliştirilen Lünenschloss test cihazında tribolojik testler yapılmış ve kenevir bazlı lif bandları üzerinde çekme dayanımı testleri gerçekleştirilmiştir. Lünenschloss test cihazı, test edilen lif malzemelerinin sürtünme katsayısını hesaplamak için sabit çekme kuvveti ölçümü kullanmaktadır. Bu test cihazının avantajı, küçük miktarlarla test yapabilmesidir. Bu sayede tek bir lif veya kısa iplik parçaları gibi minimal örnek boyutlarıyla bile güvenilir sonuçlar elde edilebilmektedir. İlk olarak, çeşitli kenevir bazlı lif bantları üzerinde, içinde polipropilen (PP) bulunanlar da dahil olmak üzere çekme dayanımı testleri yapılmıştır. Sonuçlar, PP liflerinin eklenmesinin lif bandı stabilitesini artırdığını ve bu durumun ilerleyen işlemlerde daha iyi stabilite sağlayacağını göstermektedir. Bu sonuçları doğrulamak için, Lünenschloss test cihazında sürtünme katsayıları belirlenmiştir. Bu sonuçlar, çekme dayanımı testlerinin sonuçlarıyla korelasyon göstermiştir. Genel olarak, bu ön testler, güvenilir iplik üretimi ve elde edilen iplik stabilitesi hakkında niteliksel değerlendirmeler yapılmasına olanak tanımaktadır. Bu bulgulara dayanarak, modifiye liflerin özellikleri sayesinde kaliteli ipliklerin üretilebileceği söylenebilir.

***Anahtar Kelimeler:*** kenevir, lif, sürtünme katsayısı, iplik, Lünenschloss

***Sorumlu Yazarlar/Corresponding Authors:** Seyit.Halac@rwth-aachen.de*
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## 1. INTRODUCTION

The “DuroBast” joint project is developing innovative, bio-based materials that can be used to produce structural components for various applications on a large scale. The aim of the project was to produce thermoplastically formable natural fibre composites (NFC) that should be usable in areas where natural fibres have not previously been used due to insufficient strength and high moisture absorption. [1]

The sub-project of the Institut für Textiltechnik of RWTH Aachen (ITA) studied the process development to produce low-twist yarns and textile surfaces made of hydrophobically treated fibres for the reinforcement of moisture-resistant fibre composite structural components. [2] Due to their anisotropy, fibres for NFC applications must lie in the direction of force. [3] As the fibres must lie in the same direction for this application, yarns must be produced with low twist. As low-twisted yarns have a low rotation, there is no stability due to the spiral structure of the yarn. The cohesion of the individual fibres is created solely by the friction between them. This in turn is determined by the (surface) structure of the fibre. Conclusions about the cohesion and resulting mechanical stability of the yarn can therefore be drawn by measuring the coefficient of friction. [4] For this reason, the development of alternative spinning processes in the natural fibre sector is necessary. For this purpose, slivers and low-twisted natural fibre yarns are being developed at the ITA in close cooperation with Wagenfelder Spinnereien GmbH. In this alternative spinning process, the staple fibres lying parallel to the yarn axis are wrapped with a filament. The filament prevents the stretched sliver from unravelling and generates the necessary yarn strength. This spinning process ensures that the fibres in the core of the covered yarn have an almost unidirectional fibre orientation. The fibres give the NFC product its strength and stiffness in the direction of tensile force. The low yarn twist ensures that the fibres are almost completely impregnated in the textile structure. [3]

The potential regarding the fibre composite properties will then be tested.

The research by ITA described below examines the fibre interactions of hemp fibres in combination with biopolymer fibres based on their friction values. Normally, yarns are produced by ‘trial and error’ and hope to end up with a stable yarn. To make this development process efficient, research at the ITA takes the coefficient of friction into account. The research results form a basis for assessing the properties and processability of hemp fibres to produce low-twist covered yarns.

The sample yarns are produced from pre-treated and untreated natural fibres using the covering spinning process. The spinning of low-twist yarns with a fineness of approx. 400 tex takes place on an Allma ESP 2 covering machine from Saurer AG, Arbon, Switzerland. A 78 dtex multifilament is used as the covering filament. The following types of covered yarn are spun for this sub-project:

- Yarns made from modified hemp fibres
- Yarns made from natural hemp fibres
- Hybrid yarns made from 50% hemp fibres and 50% biopolymer fibres

The manufacturing process is shown in Figure 1.

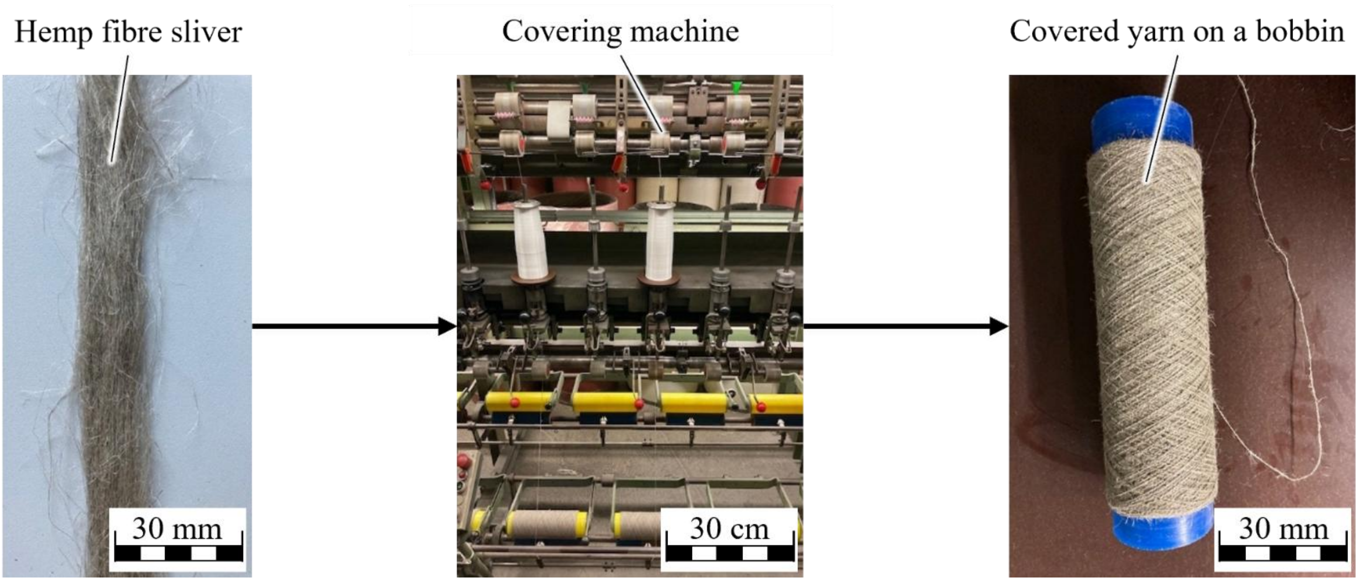



Fig. 1: Processing of hemp fibres into covered yarns

Due to high doffing speeds in the industrial production of covered yarns (up to 200 m/min), high drafting speeds are required in the drafting process. [4] The constant reduction in the number of fibres in the sliver cross-section during the drawing process makes it more difficult for the sliver to hold together due to the reduced fibre-fibre friction. The high drafting speeds result in a constant decrease in fibre-fibre friction, which leads to uneven drafting and reduces the yarn quality. [5] To evaluate the processability of the fibres in the individual process stages, tribological tests are used to analyse the fibre interactions based on their coefficient of friction. The correlation between the coefficient of friction and the stability of a yarn has been explained in the introduction. These tribological tests are discussed in the next section.

## 2. MATERIAL AND TEST METHODS

Stronger fibre-fibre friction has a positive effect on the cohesion of the fibres in the sliver and promises greater sliver stability, increased drafting quality and improved processing into yarns. [4] To determine the fibre-fibre friction of slivers and the resulting analysis of the cohesion of the sliver, adhesion-slip tests are first carried out on unmodified fibre slivers. In addition, a tribological test rig for determining the fibre-fibre friction values was developed at the ITA as part of the project. The friction values measured on this new test rig are used for a more detailed analysis of the fibre interactions. Both test methods are described below.

### 2.1 Material

The sliver and low-twist yarn samples used consist of various types of hemp-based slivers. These individual combinations are listed in Table 1.

The PP fibres with and without finishing (asota® L) were supplied by IFG asota. asota® L is a PP staple fibre produced using the melt spinning process, which was specially developed for processing into needled nonwovens, taking account of the requirements of structured qualities. The PP fibres with finish are PP staple fibres with added styrene maleic anhydride (SMA) for composite applications.

### 2.2 First test method: Fibre-fibre friction using the adhesion-slip test

For the adhesion-slip test to determine fibre-fibre friction, a fibre sliver is clamped in a tensile machine, the Favimat+ from Textechno. The clamping points move apart at a speed of v = 20 mm/min, thus stretching the fibre tape. The test ends with the tearing of the sliver. The force applied up to tearing and the elongation of the sliver allow conclusions to be taken about the adhesion-slip behaviour of the fibres. [6] The higher the force and elongation values, the higher the fibre-fibre friction in the sliver. [7] Figure 2 shows the test setup (left) and a picture taken during the test (right).

In the adhesion-slip test up to ten samples per material type were tested. The results of the adhesion-slip tests are shown in Figure 3. The fibres of sample 1 slide away from each other at an average force of 0.13 N, which leads to premature tearing of the fibre sliver. The sliver of sample 2 and the sliver of sample 3 withstand a higher load. The adhesion of the fibres of sample 4 is the strongest. They can withstand an average load of 1.82 N before they slip apart. A higher tensile force indicates the surface quality of the PP additive due to the finishing.

It has been proven that the sliver stability is increased by the addition of PP fibres with finishing. This promises a more stable drafting process, increased drafting quality and improved spinning stability in the subsequent process steps.

**Table 1.** List of the sliver and low-twist yarn samples

| Sample Number | Material designation |
|---|---|
| 1 | Fibre sliver made at the ITA from 100 % hemp from European cultivation |
| 2 | Externally purchased finished fibre sliver made from 100 % hemp |
| 3 | Fibre sliver made from a mixture of hemp & PP without finishing |
| 4 | Fibre sliver made from a mixture of hemp & PP with finishing |

The material information is shown in Table 2.

**Table 2.** Measured material characteristics

| Material designation | Fineness [g/km] | Tensile force [cN/tex] | Elongation [%] | E-Modul [GPa] | Density [g/cm³] | Fibre length [mm] |
|---|---|---|---|---|---|---|
| 100 % hemp from European cultivation | 0,1 | 39,7 | 1,9 | 35 | 1,48 | 97,7 |
| PP with finishing | 0,7 | 32,5 | 125 | / | / | 120 |

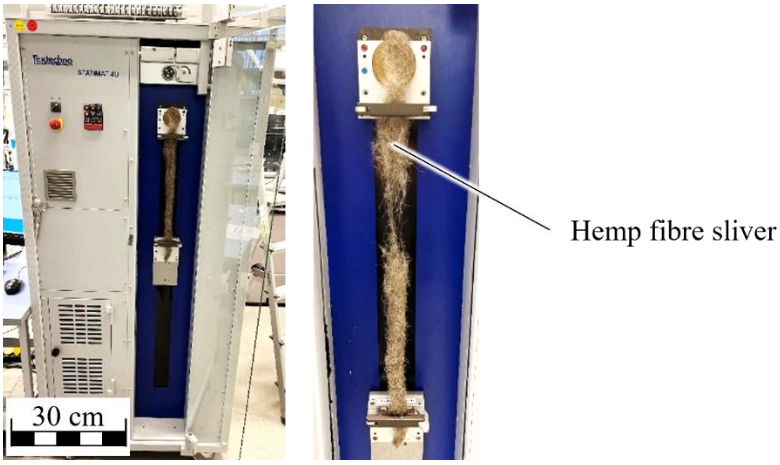
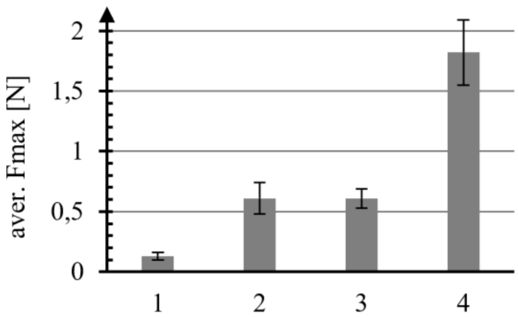



**Fig. 2.** Test setup and realisation of the adhesion-slip test

### 2.3 Second test method: Friction coefficient determination in the Lünenschloss test rig

In the previous adhesion-slip tests, higher tensile forces were determined for the sliver samples with PP additive. These observations are presumably due to the yarn-fibre interactions. To prove these assumptions, a new type of test rig was developed at the ITA to determine the coefficients of friction by measuring the static tensile force. Normally, the coefficient of friction is measured by pulling the yarn over a test specimen. Because the yarn is moved, a large amount of yarn is used. In this case, only 1 metre of yarn was available per sample. The test rig was developed in a way that the test specimen rotates and the yarn stands still. This means that only around 15 cm of yarn has to be used per test. This means that a friction coefficient measurement can also be carried out with little sample material, for example individual fibres or short pieces of yarn. The test rig can be used to draw conclusions about fibre interactions by measuring tensile forces and the resulting calculated coefficient of friction. Figure 4 shows the developed Lünenschloss test rig without power supply and evaluation electronics on the left and the corresponding principle sketch on the right.




| Sample nr. | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Tensile force aver. Fmax [N] | 0,13 | 0,61 | 0,61 | 1,82 |
| Standard deviation s [N] | 0,03 | 0,13 | 0,08 | 0,27 |
| Quantity of samples n | 7 | 5 | 5 | 10 |

**Fig. 3.** Results of the adhesion-slip tests

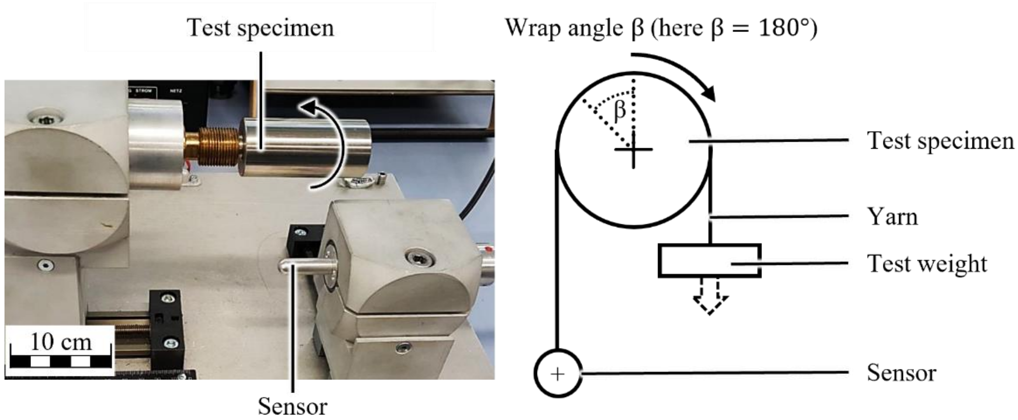



**Fig. 4.** Test setup Lünenschloss

In this test rig, a yarn is attached to a high sensitivity tensile force sensor ($F$) and guided over a steel test specimen. $\beta$ is the angle at which the yarn touches the test specimen. The yarn is weighted with a test weight at the other end of the yarn ($P_V$). In this case, the test weight was 20 cN. The test specimen rotates at a constant circumferential speed of 0.1 m/min. The coefficient of friction $\mu$ is calculated using the following formula:

$$\mu = \frac{1}{\beta} ln \frac{F + P_0}{P_v}$$

To determine the yarn-fibre friction, the surface of the test specimen is coated with a uniform layer of fibres. To be able to evaluate these measured values, comparative values are first carried out using a test specimen without a fibre layer so that the yarns are in direct contact with the steel test specimen. Then, in the first series of tests, roasted hemp fibres are used as a fibre layer. In the second series of tests, the test specimen is coated with PP fibres without finishing. Finally, the last series of tests is carried out with a layer of PP fibres with finishing. The tensile force values determined in this way are proportional to the coefficient of friction of the fibres. Three measurements were carried out for each material combination. In each test, the coefficient of friction was measured for 30 seconds while the test specimen was rotating. This generated 15,000 measured values per measurement. The average of the measurement results of each sample was used for further evaluation. The yarn samples tested are made of the same materials as the slivers used in the adhesion-slip test. The respective sample designation can be found in Table 1. Figure 5 shows the measured values of the Lünenschloss test rig: Force values on the left, coefficient of friction on the right. The standard deviation is not shown as it lies between 0,0084 and 0,0316. As the coefficient of friction provides information on the yarn stability, only the coefficients of friction are discussed below.

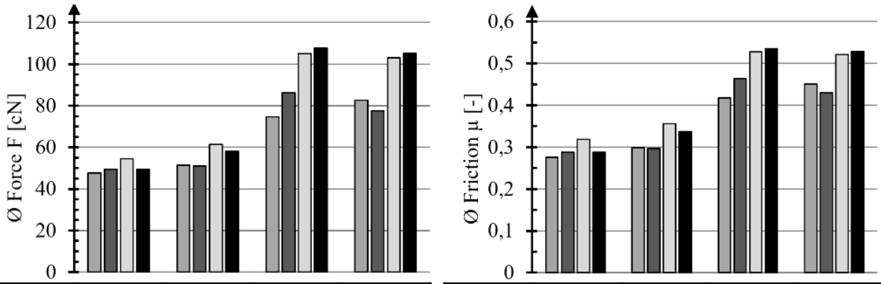
First, comparative values were determined with the steel test specimen without an additional fibre layer. Sample (1) exhibited the lowest coefficient of friction with an average value of 0.27. Similar values of 0.29 were determined for sample (2) and sample (4). Sample (3) has the highest coefficient of friction of 0.32.

The measurement results of the Lünenschloss tests with a uniform hemp fibre layer around the test specimen show that sample (1) and sample (2) have similar coefficients of friction, each being 0.29. Sample (3) has the highest friction coefficient of 0.36 and the coefficient of friction of sample (4) is 0.34. Compared to the coefficients of friction from the first measurement series, which were determined using bare steel test specimen, the values from this series of tests are generally higher. For samples (3) and (4), significantly higher coefficients of friction were measured than for the hemp yarns.

In the third test series with a uniform fibre layer of PP fibres without finishing around the test specimen, a clear increase in the coefficients of friction can be seen. Sample (1) has the lowest coefficient of friction of 0.42. The coefficient of friction of sample (2) is 0.46. The coefficient of friction of sample (4) is 0.54, which is higher than that of sample (3), which is 0.53.

The fourth measurement series was performed on the test specimen with a PP fibre layer around it. It is noticeable that the friction coefficient of sample (1) is higher than that of sample (2), 0.45 and 0.43. The PP yarn samples have the highest coefficients of friction. The friction coefficient of sample (3) is 0.52, the value of sample (4) is 0.53.

Higher coefficients of friction mean higher sliver stability and therefore promise higher yarn quality. The friction coefficient results in this test show that the samples of the yarns with PP additive (samples 3 & 4) form the greatest fibre cohesion and leads to assume better-quality yarns. This result reflects the results of the adhesion-slip tests, in which the tapes with PP additive show the highest values. The adhesion of sample (4) was the highest. These fibre properties lead to fewer interruptions in the drafting process and during yarn spinning.




| Test specimen | Steel | Steel & hemp | Steel & PP(w/o f.) | Steel & PP(w.f.) |
|---|---|---|---|---|
| Sample nr. | Ø Force F [cN] | | | |
| ▫ 1 | 47,62 | 51,40 | 74,72 | 82,69 |
| ▪ 2 | 49,52 | 50,95 | 86,20 | 77,55 |
| □ 3 | 54,62 | 61,50 | 105,06 | 102,97 |
| ■ 4 | 49,52 | 58,04 | 107,67 | 105,32 |

| Test specimen | Steel | Steel & hemp | Steel & PP(w/o f.) | Steel & PP(w.f.) |
|---|---|---|---|---|
| Sample nr. | Ø Friction µ [-] | | | |
| ▫ 1 | 0,2758 | 0,2993 | 0,4182 | 0,4502 |
| ▪ 2 | 0,2881 | 0,2964 | 0,4636 | 0,4298 |
| □ 3 | 0,3191 | 0,3558 | 0,5274 | 0,5209 |
| ■ 4 | 0,2877 | 0,3378 | 0,5357 | 0,5284 |

**Fig. 5.** Friction and force values of yarn samples in the Lünenschloss test

## 3. CONCLUSION

The goal of the tests was to analyse the fibre-fibre friction values of covered yarns made from a hemp fibre-biopolymer blend for potential processing in composite materials. For use in the NFC sector, the fibres in the yarn must lie parallel to the direction of force. For this purpose, low-twist covered yarns are used in a new type of spinning process. In the manufacturing process, the fibres are stressed by high take-off and drawing speeds in the drafting process. The fibre properties determined from the test methods presented above are intended to provide information and insights into the drafting quality and therefore the yarn quality of the respective sample. The fibre-fibre interaction is based on the friction between the fibres. A higher coefficient of friction leads to improved stability of the slivers made from these fibres, which in turn enhances the drafting process and thus has a positive effect on yarn production. Reduced yarn breakage and increased spinning stability result in fewer interruptions in the drafting process and during yarn spinning.

The low amount of yarn (1 m per material) was too small for standard friction coefficient measurements. The Lünenschloss test rig developed made it possible to circumvent this problem. This allowed reliable assumptions about the future yarn production of hemp fibre yarns based on the fibre-fibre properties. The advantage of these preliminary tests is that the lengthy, costly and material-intensive ‘trial and error’ process in yarn production can be avoided

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