IMPACT OF EXTRACTION PROCESSES ON FIBER PROPERTIES OF LINSEED FLAX FIBERS

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Abstract: *This work of a preliminary nature has for goal to investigate the potential of the linseed flax straw for industrial valorization in technical textiles. The impact of two extraction systems ("all fiber" extraction device and a scutching/hackling device) was investigated. In a first part of the paper, it was demonstrated that it is possible to extract the fibers from the other components of the straw such as the shives and vegetal dusts. The fiber yield is of about 38% of the stem mass. This very high fiber yield is particularly interesting and is higher than the one of hemp for example. The fiber properties were also investigated. The fiber length was shown to be in the adequate range of length to be considered for the carded spinning route, and the tensile properties of the individual fibers, even if decreased by about 45% in comparison to carefully manually extracted, are still at a sufficient level of performance for semi-structural composites applications for example. When using a scutching/hackling line, the length of the fibers is preserved and the impact of the fiber extraction was shown to be lower than the all fiber extraction line, particularly for the strength. These fibers could therefore be used for higher load bearing applications. Finally, the amount of fiber that can be extracted from the linseed flax fibers is large and this could certainly be at the origin of an industrial technical textile value chain.*

Keywords: *Linseed flax, all-fiber extraction, scutching/hackling, fiber characterization, tensile properties.*

1 INTRODUCTION

To manufacture high performance composite parts, it is necessary to organize and to align the fibers. As a consequence, aligned fibers architectures such as unidirectional sheets, non-crimped fabrics and woven fabrics (bidirectional) are usually used as reinforcement. For numerous applications, it is also important that the fabric may be formed into complex shapes without the appearance of defects such as wrinkles, vacancies, tow buckles etc. [1-4]. These materials are classically constituted from synthetic fibers such as glass, carbon or aramid. However, natural fibers are now considered in Europe as a serious alternative for composite reinforcement from low load up to high load bearing applications. A consequent literature, showing the interest of different fibers extracted from different plant is available. Review papers and even book chapters summarize the different progresses in the area [5-7]. A recent very complete review on the subject was proposed by Bourmaud et al. [8]. This review paper clearly shows the high potential of plant fibers and particularly bast fibers such as flax, hemp or nettles.

If the potential of the natural fibers has widely been demonstrated in numerous publications and review papers, the conversion of this potential to reality is often a problem and this one is not necessarily maximized. The maximization of the high mechanical potential of plant fibers for composite material reinforcement is dependent on several transformation steps, from the plant to the fabric. The fiber extraction step and technology used, depending on the stem arrangement, as it is illustrated by Figure 1, is a crucial key stage. It is particularly important to pay attention to the fiber extraction so that to avoid damaging the fibers to a too large extent. Specific high performance reinforcements are required to manufacture structural or semi-structural bio-composite parts especially for the automotive industry. New flax and comingled flax/bioplastic reinforcements have been elaborated in this goal. If large panels have been realised with a good success, the feasibility to manufacture complex shape parts using a sheet forming process [9], especially with natural fibre based reinforcements without defect is still a challenge. Previous studies [10-11] demonstrated that complex shape parts could be achieved by using specifically prepared fabrics, with particular process parameters. However, this requires specific care all along the different operations leading to the part manufacture due to the use of finite length natural fibres. It is also necessary when using agro-based material to reduce the impact of the part manufacturing in comparison to synthetic technology.

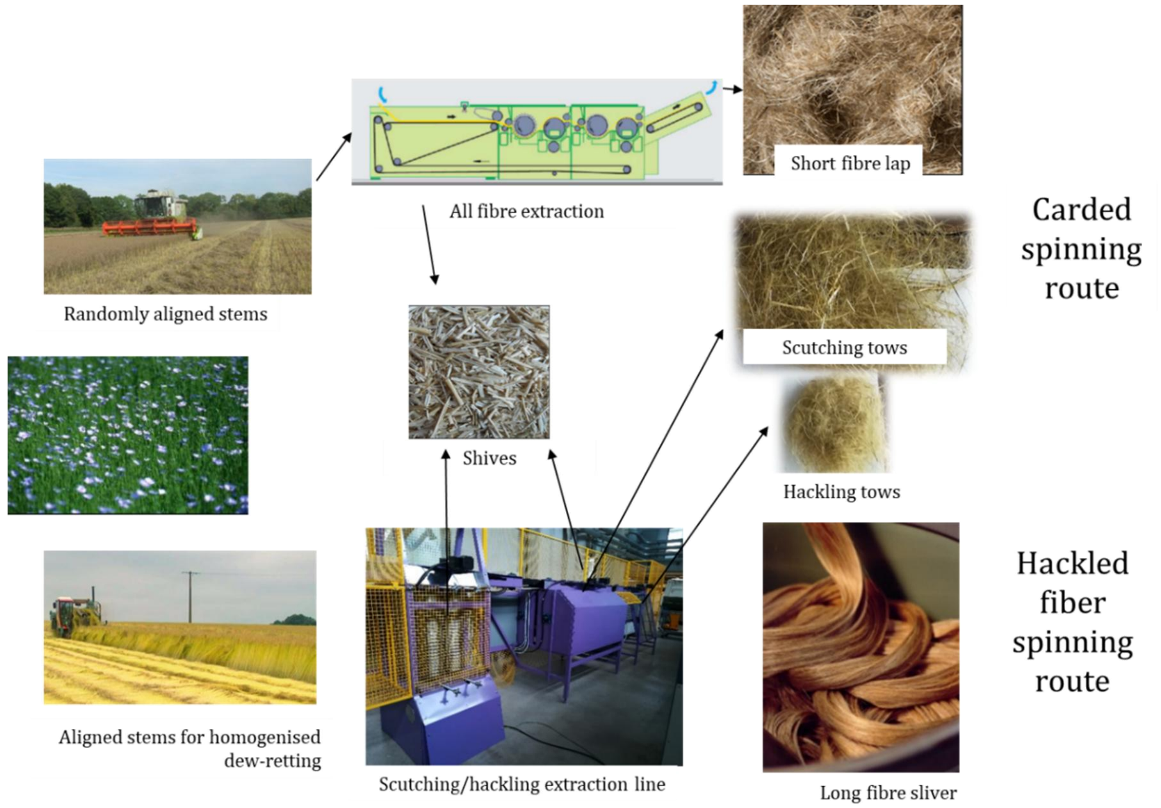

Figure 1 The fiber processing routes

The energy consumption for the production of yarn should be kept low and the possible fabric treatments should have a minimum impact on the environment. Dissanayake et al. [12] indicated that preparing composite reinforcement using natural fibers may have a higher impact on the environment than materials prepared from glass fibers if adequate manufacturing processes are not used. As a consequence, the manufacturing processes need to be adapted and optimized to reach this goal. Moreover, it is also important when considering the manufacturing processes to maximize the mechanical potential of the vegetal fibers. This means that it is important to minimize the length reduction of fibers or the appearance of defects such as dislocations or kink bands during the fiber extraction and the yarn preparation.

This paper therefore focuses on the critical and key fiber extraction stage so that to determine if the linseed flax fibers can be considered for technical textile applications. The linseed flax fibers were extracted by two different techniques and their morphological and mechanical potential characterized before and after extraction so that to determine the impact of the extraction process. Finally, the fiber yield was also studied so that to determine if an industrial value chain can be considered for the valorization of the linseed flax straw.

2 FROM THE PLANT TO THE FIBERS: IMPACT OF THE EXTRACTION PROCESSES

Within the plant, the fibers may have different roles. In flax or hemp, the bast fibers have a mechanical structural role. They contribute to the stabilization of the stems so that the plant remains vertical and that with an elongation ratio higher than the one of the highest trees. When extracted with the greatest care, the mechanical properties of the flax or hemp fibers show higher specific properties than glass fibers. However, this is only true in the case the fibers are not damaged during the different processes leading to the manufacture of the reinforcement fabric. Successive extraction and preparation processes take place before the textile architecturation into 1D (yarn) and 2D or 3D reinforcement products.

Depending on the harvesting procedures, the stems may be well ordered (textile flax or hemp in Eastern Europe) or randomly aligned (linseed flax or hemp in Western Europe). This is at the origin of different routes for the preparation of reinforcement materials. The first one, for randomly aligned stems consists in using an “all fiber” extraction line (textile fiber opener or hammer mills) that is followed by the carded preparation and spinning route. The second one is designed to receive aligned stems. It is based on the traditional well established scutching units classically used in Western Europe for flax and in Eastern Europe for hemp.

2.1 Impact of the all fiber extraction device on the morphological and mechanical properties of linseed flax fibers coming from un-retted straws.

2.1.1 The all fiber extraction device

In a preliminary study, Ouagne et al. [13] studied the potential of using an all fiber semi-industrial extraction line to extract fibers dedicated to technical applications such as semi-structural composites or geotextiles. The Laroche (France) Cadette 1000 "All Fiber" extraction opener from the AGROMAT platform (Tarbes, France), was used to extract the different vegetal fractions from linseed flax straw harvested in the south west of France. A schematic diagram of the device is presented in Figure 2.

The all fiber opening device consists of a succession of three extraction and separation modules. In each module a nailed cylinder under a rotation speed that can be up to 1700 rpm performs the fractionation of the vegetal mater into a fiber lap, shives and vegetal dusts. If the different constituent extraction is performed by the rotating nailed cylinder with the creation of a fiber lap, the shives fall on rotating belt and are sent by an aspiration system to collecting bags. In each module, a perforated cylinder extracts the fine particles through a suction process so that to separate this matter from the fiber lap. This device has the ability to process up to 175 kg of stems per hour.

2.1.2 Fiber extraction tests

Two sets of experiments were carried out on dry and rewetted by water batches. For each batch of about 25 kg of randomly aligned stem, the different fractions were weighed under similar conditions of humidity (dry state). As the fiber laps contain remaining pieces of shives trapped, these ones are removed after a mechanical sieving step and the last pieces of shives are picked up manually. Figure 3 shows the different vegetal fractions obtained at the end of the extraction process. The goal here is to evaluate the amount of fiber available from the linseed flax straws.

2.1.3 Reference material

As the goal of the study consisted in studying the impact of the extraction devices on the properties of the fibers, a reference material needs to be tested. Linseed flax fibers were extracted manually with the greatest care so that their initial potential is not decreased and represent as closely as possible the reinforcement performance of these fibers. To do so, pieces of linseed flax straws were soaked in water for 72 h under a temperature of 30°C and the fibers were extracted manually.

2.1.4 Fiber characterization: Impact of the extraction procedure on morphological and mechanical properties of technical and single fibers respectively

In a first extent, the fiber length of the technical fibers (fiber bundles) was characterized. The goal here is to investigate whether or not the technical fibers constituting the fiber lap are appropriate (sufficiently long) for a further transformation into yarns and technical textiles. The measurements were performed on about 600 fibers. To do so, one side of technical fiber was fixed and the other extremity was pulled so that to obtain a straight fiber measured between both its extremities.

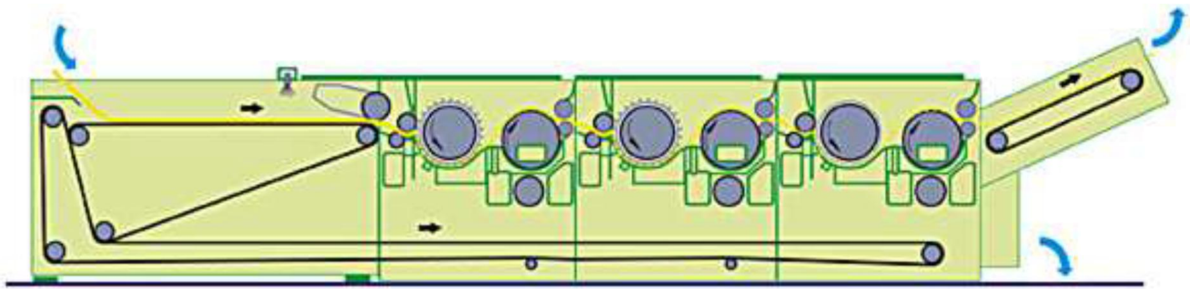

Figure 2 Schematic diagram of the three modules "all fiber" opening device

Figure 3 The three vegetal fractions

In a second extent, the evolution of the single fiber tensile properties was determined. Tensile tests on individual fibers were performed on batches of 40 fibers. The tests were performed at the FEMTO-ST laboratory following the recommendation of the NF T25-501-2 standard test method [14]. A Bose (USA) Electroforce 3230 tensile testing machine equipped with a 22 N capacity load cell was used to perform the tests. The fiber apparent diameter was evaluated using an optical microscope (Olympus PMG3-F3, France). The apparent diameters were measured at five different locations so that to calculate both tensile strength and modulus. It is assumed here that the fibers are perfectly cylindrical.

2.1.5 Results

The different vegetal fraction yields were determined after extraction processing and are presented in Table 1 for both dry and re-wetted batches.

Table 1 Fiber, shives and vegetal dust proportions after “all fiber” extraction

	Total fibre content [%]	Total shives content [%]	Total dust content [%]
Re wetted	37.5	57.6	4.9
Dry	37.8	52.4	9.8

Table 1 shows that the amount of fiber (about 38% of the stem masses) is high and much higher than what can be encountered in the literature. Indeed, the amount of linseed flax fibers in the stem is generally much lower [15]. This may be due to the fact that fiber rich stems were considered in this study, or this may be due to a different way of evaluating the fiber yields. The technical fiber lengths are presented in Table 2.

Table 2 Length of technical fibers

	Fiber bundle length [mm]
Re wetted	53±29
Dry	39±22

Table 2 indicates that the fiber bundle length is of about 40 mm for the fiber extracted from the dry stems. The fibers extracted from the re-wetted batch are longer. This suggests that it is probably interesting to re-wet the fibers before processing. This probably confers some ductility to the fibers and prevents extra breakings.

Table 3 shows the tensile properties of individual fibers manually extracted from un-processed stems and from processed bundles from the re-wetted straws.

Table 3 Tensile properties of individual linseed flax fibers

	Modulus of elasticity [GPa]	Strength [MPa]
Manually extracted	45±27	1080±640
All fiber device extration	38±17	604±409

Table 3 shows the tensile properties of the single fibers. It particularly compares the evolution of the tensile properties before and after mechanical fiber extraction with the “all fiber” device. The results indicate that the extraction has a clear impact on the tensile properties of the individual fibers. This is particularly visible for the strength with a decrease of about 45%. In the case of modulus, the decrease is more moderate (20%). This decrease in strength is probably due to the introduction of defects such as kink-bands or dislocations in the internal structure of the fibers.

2.2 Impact of a scutching/hackling extraction device on the morphological and mechanical properties of linseed flax fibers coming from un-retted straws.

2.2.1 The scutching/hackling device

A scutching/hackling device is shown in Figure 4. This device is a low scale version of classical industrial scutching/hackling units. It consists of successive breaking, scutching (beating), hackling (combing) units. The scutching and hackling devices are traditionally used when long fibers are expected.

Figure 4 Laboratory scutching/hackling line

In this work, non-retted aligned straws were collected manually to evaluate the potential of the linseed flax fibers and the impact of the scutching/hackling process on the fiber properties.

One of the main interest of using aligned stems in conjunction with scutching/hackling devices is the fact that the technical fiber length is not as much decreased as it is the case for the “all fiber” extraction line. In our case, the bundle length is about equivalent to the length of the collected stems, (about 300 mm). The fibers are therefore much longer than the ones extracted using the “all fiber” line. The hackled technical fibers are about six times longer. Figure 5 shows a sample of hackled linseed flax.

Figure 5 Hackled non-retted linseed flax sliver

If the breaking and scutching steps have an influence on the fiber properties, the most damaging stage is hackling. This stage is particularly important because it finishes the separation of the technical fibers from the rest of the stem components. It also contributes to the finer separation of the fiber bundles into individual fiber or small clusters of fibers.

The influence of the hackling step on the mechanical properties of individual fibers is given in Table 4 together with a comparison with the impact of the "all fiber" extraction.

Table 4 Tensile properties of hackled single fibers

	Modulus of elasticity [GPa]	Strength [MPa]
Manually extracted	45±27	1080±640
All fiber device extration	38±17	604±409
Scutching/hackling	***40±10***	***966±403***

Table 4 shows that the modulus does not decrease in a great extent in comparison to the manually extracted fiber. No statistical difference may be observed. The modulus of elasticity is surprisingly equivalent to the one obtained from fibers extracted with the "all fiber" device. The strength of fibers after hackling does not show any significant decrease in comparison to the manually extracted fibers. The result of the tensile strength is however much larger than the strength obtained from fiber extracted from the "all fiber" line. This suggests that the level of defects conferred to the hackled fibers is lower than the number of defects present on fibers extracted by the "all fiber" line.

3 CONCLUSIONS

This work of a preliminary nature has for goal to investigate the potential of the linseed flax straw for industrial valorization in technical textiles. The impact of two extraction systems ("all fiber" extraction device and a scutching/hackling device) was investigated. In a fist part of the paper, it was demonstrated that it is possible to extract the fibers from the other components of the straw such as the shives and vegetal dusts. The fiber yield is of about 38%. This very high fiber yield is particularly interesting and is higher than the one of hemp for example [15]. The fiber properties were also investigated. The fiber length was shown to be in the adequate range of length to be considered for the carded spinning route and the tensile properties of the individual fibers even if decreased by about 45% in comparison to carefully manually extracted are still at a sufficient level of performance for semi-structural composites applications for example. When using a scutching/hackling line, the length of the fibers is preserved and the impact of the fiber extraction was shown to be lower than the all fiber extraction line, particularly for the strength. These fibers could therefore be used for higher load bearing applications. Finally, the amount of fiber that can be extracted from the linseed flax fibers is large and this could certainly be at the origin of an industrial technical textile value chain.

4 REFERENCES

1. Potter K., Khan B., Wisnom M., Bell T., Stevens J.: Variability, fibre waviness and misalignment in the determination of the properties of composite materials and structures, Composites Part A 39(9), 2008, pp. 1343-1354, https://doi.org/10.1016/j.compositesa.2008.04.016
2. Ouagne P., Soulat D., Moothoo J., Capelle E., Gueret S:. Complex shape forming of a flax woven fabric; Analysis of the tow buckling and misalignment defect, Composites Part A 51, 2013, pp. 1-10, https://doi.org/10.1016/j.compositesa.2013.03.017
3. Tephany C., Gillibert J., Ouagne P., Hivet G., Allaoui S., Soulat D.: Development of an experimental bench to reproduce the tow buckling defect appearing during the complex shape forming of structural flax based woven composite reinforcements, Composites Part A 81, 2016, pp. 22-33, https://doi.org/10.1016/j.compositesa.2015.10.011
4. Ouagne P., Soulat D., Tephany C., Gillibert J.: Measurement of the appearance and growth of tow buckling defect in the frame of complex shape manufacturing process by using fringe projection technique, Strain 52(6), 2016, pp. 559-569, https://doi.org/10.1111/str.12206
5. Dhakal H.N., Zhang Z.: The use of hemp fibres as reinforcements in composites, Biofiber Reinforcements in Composite Materials, Woodhead Publishing, 2015, pp. 86-103, https://doi.org/10.1533/9781782421276.1.86
6. Mussig J., Haag K.: The use of flax fibers as reinforcements in composites, Biofiber Reinforcements in Composite Materials, Woodhead Publishing, 2015, pp. 35-85, https://doi.org/10.1533/9781782421276.1.35
7. Akin D.E.: Flax - Structure, Chemistry, Retting and Processing, Industrial Applications of Natural Fibres: Structure, Properties and Technical Applications, Wiley publication, 2010, pp. 89-108, https://doi.org/10.1002/9780470660324.ch4

8. Bourmaud A., Beaugrand J., Shah D.U., Placet V., Baley C.: Towards the design of high-performance plant fibre composites, Progress in Material Science 97, 2018, pp. 347-408, https://doi.org/10.1016/j.pmatsci.2018.05.005
9. Ouagne P., Soulat D., Hivet G., Allaoui S., Duriatti D:. Analysis of defects during the preforming of a woven flax reinforcement, Advanced Composite Letters 20(4), 2011, pp. 105-108, https://doi.org/10.1177/096369351102000403
10. Capelle E., Ouagne P., Soulat D., Duriatti D.: Complex shape forming of flax woven fabrics: Design of specific blank-holder shapes to prevent defects, Composites Part B 62, 2014, pp. 29-36, https://doi.org/10.1016/j.compositesb.2014.02.007
11. Allaoui S., Hivet G., Soulat D., Wendling A., Ouagne P., Chatel S.: Experimental preforming of highly double curved shapes with a case corner using an interlock reinforcement, International Journal of Materials Forming 7(2), 2014, 155-165, https://doi.org/10.1007/s12289-012-1116-5
12. Dissanayake N., Summerscales J., Grove S., Singh M.: Life cycle impact assessment of flax fibre for the reinforcement of composites, Journal of Biobased Materials and Bioenergy 3(3), 2009, pp. 245-248, https://doi.org/10.1166/jbmb.2009.1029
13. Ouagne P., Barthod-Malat B., Evon P., Labonne L., Placet V.: Fibre extraction from oleaginous flax for technical textile applications: Influence of pre-processing parameters on fibre extraction yields, size distribution and mechanical properties, Procedia Engineering 200, 2017; pp. 213-220, https://doi.org/10.1016/j.proeng.2017.07.031
14. ASTM D3822 / D3822M – 14. Standard Test Method for Tensile Properties of Single Textile Fibers
15. Meirhaeghe C.: ADEME Report: Assessment of natural fibre availability and accessibility for material uses in France, 2011, http://www.ademe.fr/sites/default/files/assets/documents/76290_12_evaluation_dispo_accessibilite_fibres_veg_usages_materiaux.pdf