DETERMINATION OF THE OPTIMAL FLAX FIBRE PREPARATION FOR USE IN UD-EPOXY COMPOSITES

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1 General Introduction

Flax fibres are an interesting alternative for the widely used glass fibres. The specific stiffness of flax fibres is higher than for glass, which indicates a possible weight benefit[1]. Flax fibres are a natural renewable material (it takes only 100 days to reach his full height). During growth and the process from stem to fibre the total used energy is very limited (±10MJ/kg) compared to glass (55MJ/kg)[2]. In extra the culture of the flax is a very environmental friendly culture, which needs no irrigation and almost no pesticides and nutrients.

Although the high potential of the flax fibres, the use of them in composites is very limited. The main reason is the limited length of flax fibres, which makes it necessary to apply twist on the fibres in order to obtain a continuous yarn. The presence of the twist leads to a drastic decrease in mechanical properties, especially for the stiffness.

In this work the influence of the twist on the mechanical properties of flax fibres is investigated. Therefore flax from different stages in the fibre production process are taken, each with a different amount of twist. Attention is paid to the properties of the produced composites, but also to the dry strength, which is higher when more twist is applied. The main goal is to check if the use of flax which is not processed until a yarn is useful for composites.

2 Experimental work

2.1 Materials

Four different flax fibre bundles are taken, they are shown in Figure 1:

Hackled flax: which is delivered in a ribbon, without twist

Doubled flax: ribbon without twist, mixture of different hackled ribbon and therefore more homogeneous

Roving: a bundle of fibres, with low twist

Yarn: bundle of fibres with high amount of twist

The matrixmaterial used in the composites is an epoxy: *Resin XB 3515 / Aradur® 5021* from Huntsman.

2.2 Experimental procedure

First the fibre bundles are characterized: the twist angle and the dry strength are measured. Afterwards UD composites are produced with an epoxy matrix. These composites are tested in fibre direction to investigate the influence of twist on stiffness and strength. By applying the rules of mixture the fibre bundle stiffness and strength is calculated from the stiffness and strength of the composite

2.3 Results

The properties of the dry fibre bundles can be found in Table 1. For the two materials without twist the mentioned diameter is in fact the width of the ribbon. The strength of the dry fibre bundles is measured with a gauge length of 1m, to assure that also the cohesion between the different technical fibres in the bundles is tested and not the strength of the fibres themselves. This cohesion between the fibres is important for possible textile techniques like weaving. From the results in Table 1 it is clear that a higher twist increases the strength of the dry fibre bundle which increases the possibilities for composite production. Also the failure mechanism is completely different, while the twisted bundles fail suddenly, when a fibre breaks, the untwisted fibre bundles are sliding out of each other. Therefore the mentioned values are in fact just the friction between the different fibres that is measured.

The composites are produced by producing prepregs which are afterwards consolidated in an autoclave process. The prepregs with the hackled flax are produced on a hot melt prepregger. Because of the limited strength of the hackled flax it is important not to pull on the fibres itself during the production but on a transport paper. The yarns and rovings are stronger and they can be used on a drumwinder, to produce the prepregs. Because of the limited strength of the doubled flax , the drumwinder cannot be used. It should be possible to use the material on the prepregger, but due to the limited amount of material this is not investigated.

From the different prepregs UD laminates are produced with an autoclave. Therefore the prescribed curing cycle is applied. The properties of the different plates differ a lot. This variation is due to a different fibre volume fraction. The fibre volume fraction (Vf) of the produced composites is calculated from the weight fraction. Based on the linear density of the flax fibre bundles and the total length of the plate, the weight of flax per m² is known. Taking into account the weight of the composite plate and the flax density (1,45g/cm³) the Vf is obtained.

When Vf is known the rule of mixture can be used to calculate the properties of the fibre bundle. The calculated fibre bundle stiffness and strength are summarized in Table 2. It can be seen that the untwisted hackled flax has by far the best properties. Rovings have better properties than yarns, stiffness as well as strength are 20 % higher for the rovings. However the properties of hackled flax are still 20% higher compared to rovings.

The above mentioned values for the stiffness are measured in the deformation are between 0.3 and 0.5%. Normally the stiffness should be calculated in between 0.1 and 0.3% strain. However it seems that in this region a stiffness drops occurs (Figure 2) . If the stiffness is calculated in the very first part of the deformation, between 0.05 and 0.1%, the stiffness values increase about 30%, see Table 3.

An explanation for stiffness reduction could be the onset of damage in the fibre bundles, in the matrix or at the fibre matrix interface. If this early damage would be present, the stiffness decrease would be irreversible. In this case the stiffness must be calculated in the 0.05 – 0.1% strain region because the stiffness is defined in the elastic region. Therefore a small investigation is done to check if the stiffness drop is reversible.

Some samples are loaded up to 0,4% strain. This is higher than the deformation where the stiffness decrease occurs. The samples are subsequently unloaded and reloaded again until failure occurs. The stress-strain graphs of these 2 cycles are identical, which means that the stiffness decrease also occurs in the 2nd loading. Therefore, it can be concluded that the observed stiffness decrease is caused by a reversible mechanism, and that the elastic strain limit is higher than 0,4%. This means that the stiffness calculation between 0,3 and 0,5% strain is acceptable.

Although hackled flax gives the best properties in composites, there are also some disadvantages. The hackled flax is not very homogeneous, leading to a non homogeneous distribution of the fibres in the composites. This is not seen in the longitudinal properties but will have an influence on the transverse properties. Another problem is that in the hackled flax the fibres are still gathered in big bundles, while they are separated finer in a roving (Figure 3 and Figure 4). These big fibre bundles will lead to stress concentrations.

In the image of the composite with the roving the different rovings are almost unrecognizable. This is due to the low twist which gives a very open structure. On the other hand in a composite with the yarn the yarns are very easy to recognize (Figure 5). The high twist of the yarns lead to a very stable and closed yarn, which is difficult to impregnate. This leads to a very inhomogeneous fibre distribution, and higher stress concentrations. Therefore it seems better to use the rovings instead of the traditionally used yarns when flax fibres are used as reinforcement.

3 Conclusion

The use of flax fibres in composites is very limited despite their high potential. One of the reasons is the applied twist in the yarns. This problem can be solved by using flax fibres from earlier in the fibre

production process. By using rovings instead of yarns an increase in stiffness and strength of 20% is possible. The dry strength of rovings is lower than that of yarns, but high enough to make an easy production of composites possible. An extra advantage of using the rovings is the more homogeneous distribution of the fibre in the composites, compared to the fibres in a yarn.

Figure 1: The 4 different fibre bundle types: (from left to right) hackled flax, doubled flax, roving and yarn.

Table 1: Properties and the strength of the different dry fibre bundle types

Fibre bundle type	Linear density [tex]	Twist [m^{-1}]	Twist angle [°]	Breaking force [N]	Specific strength [cN/tex]	Strength [MPa]
Hackled flax	24 000	0	0	19	0,08	1,20 ± 0,57
Roving	276	41	7,8	11	4	59 ± 12
Doubled flax	4 800	0	0	3	0,06	0,9 ± 0,7
Yarn	78	280	19,4	19	24	350 ± 65

Table 2: Longitudinal mechanical properties from the different fibre bundle types.

Fibre bundle type	Production method	Calculated fibre bundle stiffness [GPa]	Calculated fibre bundle strength [MPa]
Hackled flax	Prepregger	62,9	844
Roving	Drumwinder	51,4	738
Yarn	Drumwinder	43,1	589

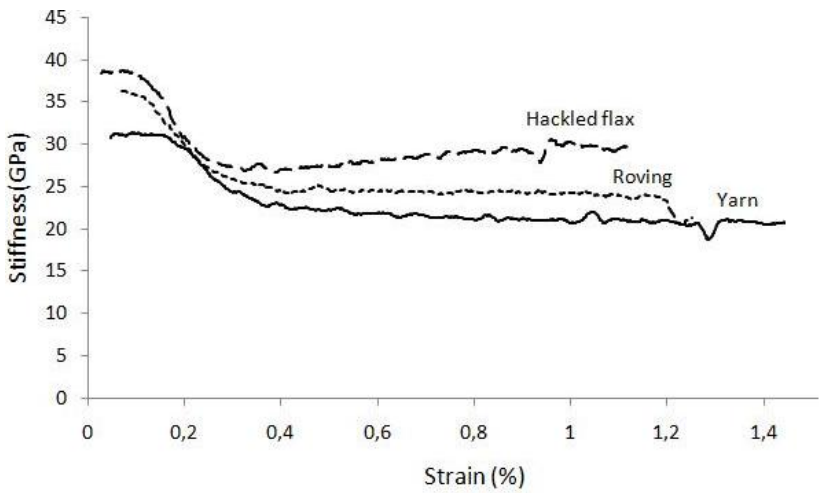

Figure 2: The evolution of the stiffness in function of the deformation for the different produced composites.

Table 3: Mechanical properties of the different fibre bundles and their composites, calculated in the first deformation area (0.05 - 0.1%).

Fibre bundle type	Production method	V_f [%]	Stiffness [GPa]	Calculated fibre bundle stiffness [GPa]	Calculated fibre bundle strength [MPa]
Hackled flax	Prepregger	42 ± 2	39,9 ± 3,4	90,1	860
Roving	Drumwinder	48 ± 1	36,6 ± 2,1	72,9	751
yarn	Drumwinder	50 ± 1	32,0 ± 1,8	61,0	600

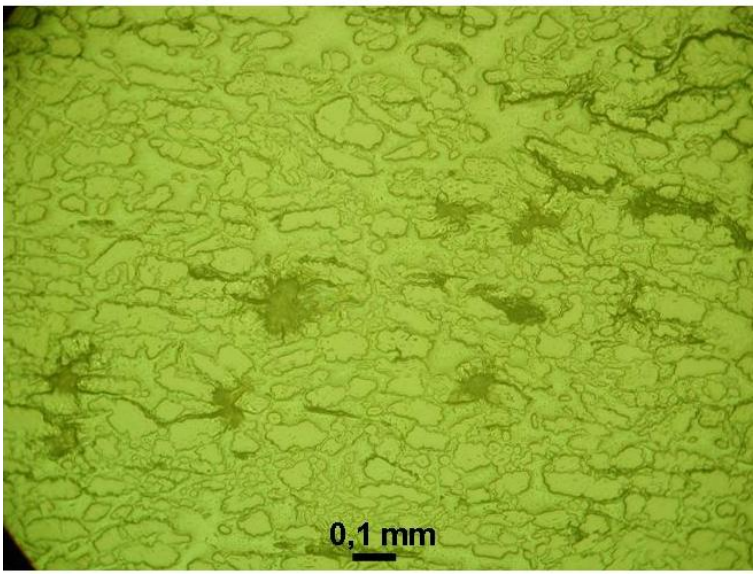

Figure 3: Cross-section of a hackled flax composite (prepregger, Vf=42%)

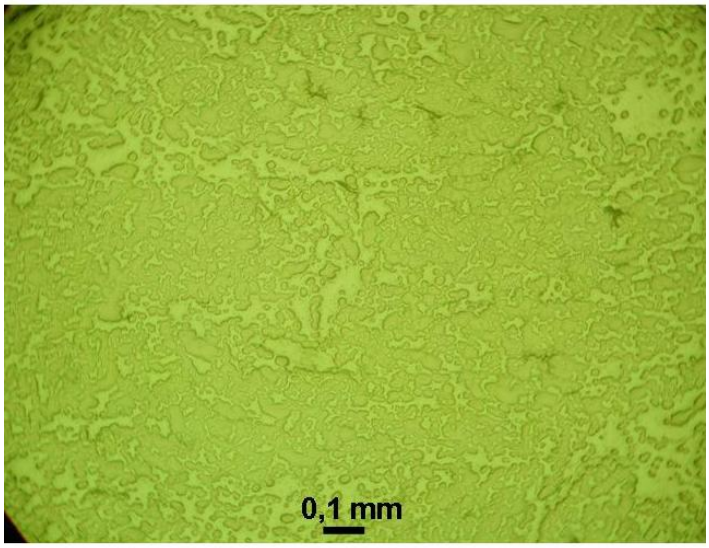

Figure 4: Cross-section of a flax roving composite (drumwinder, V_f=48%)

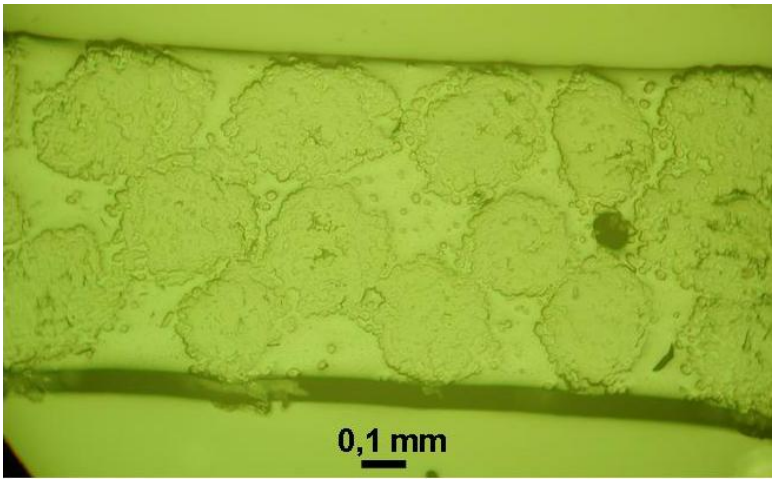

Figure 5: Cross-section of a flax yarn composite (drumwinder, V_f=50%)

References

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