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TWISTING OF FIBRES IN YARNS FOR NATURAL FIBRE COMPOSITES

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1 Introduction

The perspective of using natural fibres (such as flax, hemp, jute or wood) as reinforcements in polymer matrices is to have an alternative to traditional glass fibre based composites with an eco-friendly profile [1]. Therefore, optimization of natural fibres for composite applications is a field of great interest. There is great potential in these natural fibres as the theoretical reinforcement capability indicates that natural fibre composites can be a competitive alternative to glass fibre based composites. However, so far it has not been possible to fully utilize the natural fibre properties when using them for composite applications. As such, the present study is carried out with the overall purpose of contributing to optimizing natural fibre composites for load-bearing applications.

Natural fibres used for reinforcement in polymer composites are generally relatively short. For instance, hemp and flax fibres are no longer than 5-8 cm of length. Thus, to be able to position and process the fibres, they are traditionally spun into yarns by the technique of ring-spinning where a bundle of parallel fibres are twisted into a helical configuration. Thereby, the friction between the individual fibres ensures the integrity of the yarn. However, this spinning introduces an off-axis misalignment between the principal axis of the yarn and the constituting fibres see Fig. 1. It is known that for unidirectional glass fibre reinforced polymer composites, only a few degrees of misalignment results in a marked decrease in mechanical (elastic, strength) properties [2]. This begs the question: “Does the spinning of natural fibres into yarns mean that natural fibre composites do not fully realize their potential?” The present study investigates a part of this question be studying the influence of fibre yarn twisting on the stiffness of natural fibre composites.

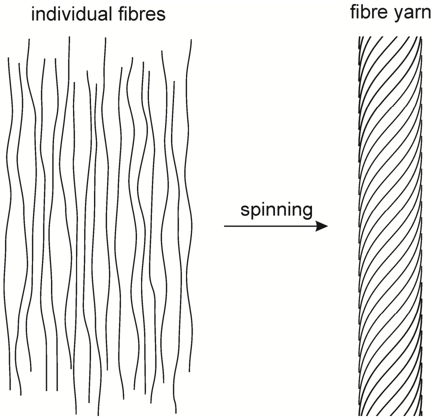

Fig. 1. Illustration demonstrating the effect of fibre spinning. Left: Assembly of parallel fibres. Right: Spun yarn made of twisted fibres.

2 Experimental

2.1 Materials

2.1.1 Fibre reinforcements

Natural fibre yarns specifically designed for composite usage has recently been made commercially available. In these so-called zero-twist yarns, the fibres are kept together by a thin polymer filament that is wrapped around the assembly of non-twisted fibres. Thus the integrity of the yarn does not rely of friction between fibres (as is the case for traditional ring-spun yarns), and the fibres can be positioned parallel to the principal axis of the yarn. For the experiments, zero-twist yarn supplied by Composites Evolution, UK was used. The natural fibres were flax fibres and the wrap filament was made of polyethylene terephthalate (PET). The linear density of the yarn was 235 tex (g/km). A yarn twisting machine (Agteks DirecTwist) was used to introduce a variety of twisting angles into the yarn. This was done at Designskolen Kolding, Denmark. Six types of yarn were made with twisting angles ranging from 5° to 25°. The twisting machine operates in twists pr. meter, whereas the interesting parameter in the present study is the fibre twisting angle. An analytical correlation between these two parameters is found in [3].

2.1.2 Matrix

A special grade of polyethylene terephthalate, called LPET (supplied by Comfil, Denmark) was used as matrix in the composites. LPET differs from standard PET in that it has a relatively low melting temperature of 180˚C compared with >250˚C for standard PET. Flax fibres are known to degrade when being exposed to temperatures above 200˚C [4]. The LPET matrix material was in the form of continuous filaments with a linear density of 56 tex.

2.2 Processing of composites

2.2.1 Filament winding

Composite materials were manufactured using the filament winding method [3], where flax fibre yarns and LPET matrix filaments were wound on a steel frame. The ratio of fibre yarns to matrix filaments in the fibre/matrix assembly was such that a fibre volume fraction of 0.35 was achieved in the resulting composite panels. Some advantages of using this technique are very good fibre yarn alignment, and high versatility in the attainable fibre volume fractions. After the winding process, the fiber/matrix assembly was dried under vacuum for 24 h.

2.2.2 Press consolidation

Press consolidation of the composite panels was carried out in a two-step process. To melt the matrix, the assembly was first heated to 190°C under vacuum for 10 minutes. This was followed by press consolidation at a pressure of 800 kPa for 3 minutes, at a temperature of 30°C. By this process, seven composite panels were manufactured. One from each of the six twisted yarns, and one from the un-twisted yarn. The panels had the dimensions 2 mm x 250 mm x 400 mm (thickness x width x length). From each panel, six tensile test specimens of dimensions 2 mm x 25 mm x 180 mm were cut with the fibre yarns oriented in the tensile directions. These specimens were conditioned in a climate chamber for 40 days at 23°C and 50 % relative humidity before mechanical testing.

2.3 Materials characterization

2.3.1 Electron microscopy

To determine the fibre twisting angles of the differently twisted flax fibre yarns, scanning electron microscope (SEM) images of the yarns were made with a table-top SEM (Hitachi TM-1000). Yarn samples were attached to the standard specimen holder with double-sided adhesive carbon tape. The samples were not coated, as the SEM was operated in ‘charge-reduction mode’ which minimizes charge build-up. The images were then analyzed in Image-Pro 5.0, where the angles between individual fibres and the primary axis of the yarn were determined. Between 30 and 85 determinations of the fibre twisting angle were made for each of the flax yarns.

2.3.2 Optical microscopy

Three samples with dimensions 30 mm x 30 mm were cut from each composite panel. These samples were polished on a polishing machine (Struers DP-04) on the surface perpendicular to the fibre yarn direction. These surfaces were then observed in an optical microscope (Leitz Aristomet). Thereby, it was possible to evaluate the microstructure of the composite materials.

2.3.3 Porosity content determination

For each composite panel, three samples with dimensions 15 mm x 15 mm were cut. These samples were used to determine the density of the composite material. The densities were determined by the buoyancy method (Archimedes principle) using water as the displacement medium. A high precision balance set (Mettler-Toledo XS204) was used. Based on data for densities of the flax fibres and the LPET matrix, in addition to data for the flax fibre weight fraction used in the filament winding process, the volume fractions of fibres and matrix in the composite panels were calculated. The composite porosity content was estimated as the volume fraction not taken up by the fibre and matrix components.

2.3.4Mechanical testing

The test specimens were tested under uniaxial tensile loads in the yarn direction on an electrodynamic tensile testing machine (Instron ElectroPuls E3000) fitted with a ±5 kN load cell (Dynacell). Strain was measured with two extensometers (Instron 2620-603), one on each side of the specimen. The extensometers had gauge lengths of 50 mm. The specimens were not tested until failure, but only to a strain of 0.25 %. The displacement rate was 1 mm/min, and the readings from the load cell and the extensometers were recorded with a frequency of 10 Hz. In order to evaluate how the stiffness of the composites depend on the fibre twisting angle in the flax yarn, the Young's modulus was found from the recorded stress-strain curves for all specimens. This was done by fitting a linear function to the stress-strain data in the linear region from 0.01 % strain to 0.1% strain.

3 Results

3.1 Fibre twisting angle

Fig. 2 shows an SEM image of the original yarn which has not been subjected to twisting. From the image it is clear that the natural fibres are aligned in a parallel configuration being kept together by the PET wrap filaments.

Fig. 3 shows SEM images of the un-twisted yarn, and the six yarns that were subjected to different degrees of twisting to give fibre twisting angles in the range between 5 and 25º. It is seen that the fibre twisting angle is increasing with the number of turns per meter.

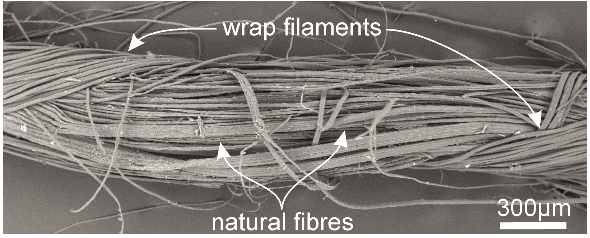

Fig. 2. SEM image showing the un-twisted flax fibre yarn.

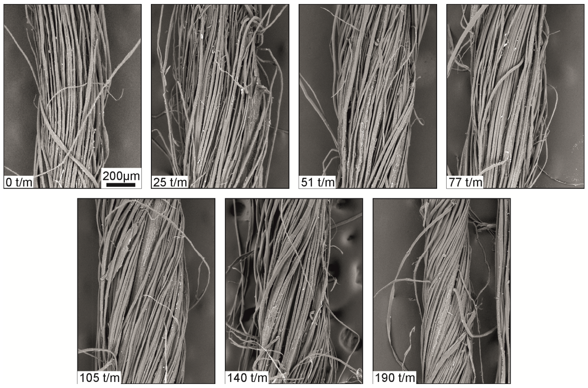

Fig. 3. SEM images of the differently twisted flax fibre yarns. Indicated are the levels of twisting in unit of turns per meter (t/m). As an example, 190 t/m corresponds to a fibre twisting angle of 25º.

3.2 Microstructure of composites

Fig. 4 shows an example of a picture from the optical microscopy of the polished composite specimens. A number of features can be identified. As indicated with the punctuated circle on the picture, the flax fibres are arranged in semicircular fibre yarns. Within these yarns, a number of fibre bundles of unseparated fibres are seen. Next to each yarn, the PET wrap filaments are seen. Furthermore, a number of porosities are seen. These are primarily seen at the edges of fibre bundles. Apart from these porosities, the wetting of the flax fibres by the LPET matrix is assessed to be very good.

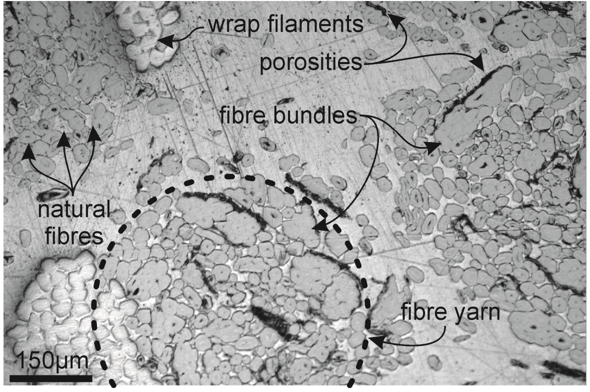

Fig. 4. Optical microscope image showing the microstructure of a 190 t/m yarn composite sample.

3.3 Porosity content

The porosities of the composite panels with the differently twisted flax fibre yarns were found to be between 0.91 and 1.53 %, as shown in Fig. 5.

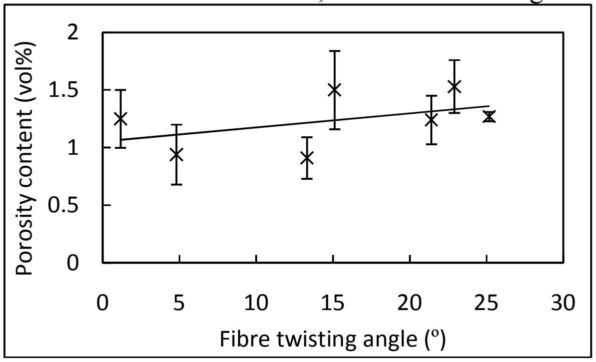

Fig. 5. Plot showing the relation between the fibre twisting angle and the composite porosity content.

A linear tendency line has been included in the diagram to point out the slight tendency for the porosity content to increase when the fibre twisting angle is increased.

3.4 Composite tensile stiffness

The relation between the composite stiffness and the fibre twisting angle are shown in the plot in Fig. 6. The Young's modulus values for the six twisted yarns vary between 14.7 and 16.0 GPa with no obvious pattern, while a value of 12.6 GPa is found for the un-twisted yarn. Generally, relatively low standard deviations (1.9 - 3.7 %) are seen.

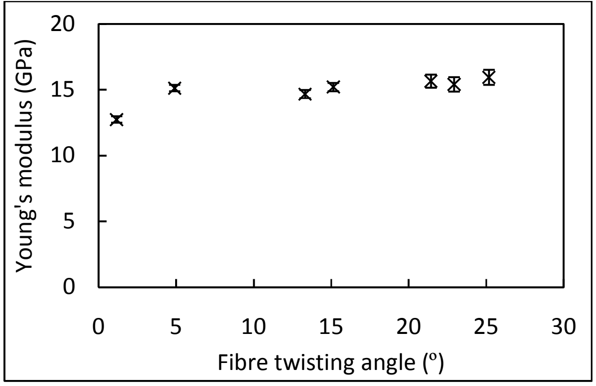

Fig. 6. Plot showing the relation between the composite stiffness and the fibre twisting angle. The data point at 1° belongs to the un-twisted yarn.

4 Discussion

In Fig. 4 it is seen that a number of large fibre bundles (sometimes referred to as 'technical fibres') are present in the fibre yarns. Such fibre bundles have been seen to cause an increased tendency for the composite to develop fibre/matrix interface splitting damage [5]. Indeed, the majority of porosities present in Fig. 4 are seen at the interfaces of these fibre bundles. It can be speculated that the porosities are artifacts from to polishing. However, the fact that they appear at the fibre bundles illustrates that these fibre bundles are vulnerable to damage.

It was found that for the low levels of twist, the fibres are configured in the yarn in a relatively loose structure. When the degree of twisting is increased, the fibres become more tightly configured in the yarn. This tendency is seen in Fig. 3 where especially the 190 t/m yarn seems to have a relatively tight fibre configuration. It seems reasonable to assume that the tighter the fibre configuration, the harder it is for the matrix to impregnate all the fibres in the yarn. Thus, a higher porosity content is expected for the composites with the highly twisted yarns. Investigating Fig. 5, this effect can be seen, although it is relatively weak, and the standard deviations are relatively large. This effect could be investigated further be making a series of composite panels with a higher fibre content, where the tendency to develop porosities would be more pronounced.

From Fig. 6 it is seen that no relation could be found between the composite stiffness and the fibre twisting angle. This indicates that the fibre yarns in the composites behave a solid 'rods' instead of assemblies of individual fibres. This is an interesting result, which needs to be explored further. Indeed, the authors of the present study are currently doing further investigations by using a zero-twist flax fibre yarn with a polylactic acid (PLA) wrap filament. These wrapping filaments will melt during processing of the composites, and this will allow the flax fibres to disperse more homogenously in the composites. It is speculated that this improved dispersion of the fibres will result in composites with improved stiffness and strength properties, and possibly they will also show some dependency of the fibre twisting angle, as the twisted yarns will have a limited dispersion capability.

5 Conclusions

The present study offers some preliminary results on the relation between composite stiffness and the fibre twisting angle for unidirectional flax fibre yarn composites. It was found that the fibre twisting angle does not influence the composite stiffness. It was speculated that a homogeneous dispersion of the natural fibres might give better material stiffness properties.

Acknowledgements

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References

[1] C. Baillie (Ed) "Green composites: Polymer composites and the environment". Woodhead Publishing, Cambridge, 2009.

[2] B.D. Agarwal, L.J. Broutman "Analysis and performance of fiber composites", 3rd edition. John Wiley and Sons, 2006.

[3] B. Madsen, P. Hoffmeyer, A.B. Thomsen, H. Lilholt. "Hemp yarn reinforced composites - I. Yarn characteristics". Compos Part A, Vol. 38, pp 2194-2203, 2007.

[4] P.R. Hornsby, E. Hinrichsen, K. Tarverdi. "Preparation and properties of polypropylene composites reinforced with wheat and flax straw fibres - Part I Fibre characterization". J Mater Sci, Vol. 32, pp 443-449.

[5] M. Rask, B. Madsen, B.F. Sørensen, E.M. Lauridsen. "In situ observations of microscale damage evolution in natural fibre composites". *Submitted to Compos Part A.*