Preliminary Investigation into Tensile Characteristics of Long Flax Fibre Reinforced Composite Material

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Abstract. Natural fibre composites are materials formed by polymer resin matrix and reinforced with natural fibres mainly formed by cellulose, originating thus from plants, such as hemp, jute, flax, sisal, banana, etc. The advantage of natural fibre materials is their biodegradability and the fact that they are a renewable resource.

In Estonia, the most common plant for natural fibre manufacturing has been flax due to its long tradition of cultivation. Flax is currently no longer grown for textile production because of the economic situation, although the weather conditions are very suitable. Nevertheless, flax is still cultivated in small quantities for linseed oil production in Estonia. Experimental methods for manufacturing non-woven industrial textiles like felt and mats from short flax fibres are depicted. Long flax fibres were used as reinforcement in matrix of epoxy resin for experimental manufacturing of natural fibre reinforced composite material. The most important characteristic of all non-woven materials is tensile strength. The results of the tested natural fibre composite materials are presented. The potential fields of application for long flax fibre reinforced composite material are car, marine and windmill industry.

Key words: Natural fibres, flax, non-woven textile, natural fibre composites

INTRODUCTION

Market demand for environmentally friendly products is growing. The usage of plant fibres is often associated with an eco-design initiative for introducing environmentally friendly materials (Dweib et al., 2004). The advantages of natural fibres over synthetic or man-made fibres, such as carbon and glass, are the low density, low cost, acceptable specific strength properties, biodegradability, ease of separation, and carbon dioxide sequestration (Mohanty et al., 2005). The relative sustainability of biocomposites should be observed at all stages of development. The environmental, economic and social impacts should be evaluated for better understanding of the advantages of natural fibre based bio composites. Bio composites should be compostable at the end of life. All possible solutions for end-of-life products, such as mechanical recycling, incineration and composting should be considered. Composting presumes biodegradable resin matrix, which is appropriate for natural fibre reinforcement (Wallenberg et al., 2004). The relationships between natural fibre properties and resin matrix properties are more complex than those in glass fibre reinforced composites (Hagstrand et al., 2004). Injectable short-fibre thermoplastic compounds are commercially available on the market, but high-performance thermosetting composites with long natural fibre reinforcement are still in a development phase in research laboratories (Bos et al., 2006).

Mechanical properties of bio composites achieved by natural fibre reinforcement are equally important. Natural fibre properties of are influenced by many factors, including plant type and variety, growth conditions and method for extracting fibre bundles (Mohanty et al., 2005).

Traditional production and primary processing techniques have been developed over a long period of time. The main application is production of high value long fibre material for the textile industry (Zhang et al., 2000).

The application of flax fibres in the production of nonwovens is connected with the adaptation of non-linen spinning systems, i.e. with the need for the following operations: cleaning, dividing and shortening of fibres. The application of appropriate blends of fibres would enable their processing as nonwovens with the use of traditional nonwoven machinery lines (Muir et al., 2003).

Flax (*Linum usitatissimum*) can be grown for linseed or fibre production at very high densities to produce high, unbranched stems. Flax fibre is a cellulose polymer, but its structure is more crystalline, making it stronger, crisper and stiffer to handle, and more easily wrinkled (Soiela, et al., 2003). Flax fibres range in length up to 90cm, and average 10 to 20 microns in diameter (See Fig. 1).

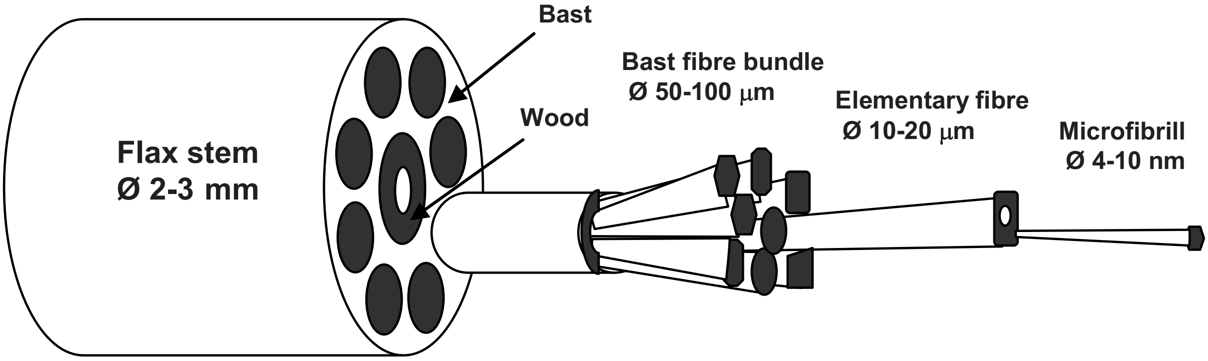

Fig. 1. Internal structure of a flax stem.

High quality fibres are obtained from the upper third of the stem to the base. As the fibre is bast-type, it must be retted to release fibres which are then bleached before use.

Removal of straw from flax fibres is called dressing, which consists of three steps: breaking, scutching and heckling. Breaking breaks up the straw, after which some of the straw is scraped from the fibres in the scutching process; then the fibre is pulled through various different sized hackles to remove the last bits of straw. Enzymes have the potential to provide an improved method of flax retting for textile fibres (Faulk et al., 2008).

Flax fibre is hollow and absorbs up to 12 wt% in water, but it dries quickly. In comparison with synthetic fibres, such as fibreglass, flax fibre is anti-static by nature and does not perspire. The fibres are twice as strong as those of cotton and five times stronger than those of wool. When flax fibre gets wet, the strength of fibre increases by 20%. The mechanical properties of synthetic and natural fibres are compared in Table 1.

Table 1. Physical and mechanical properties of natural and man-made fibres (Mohanty, 2005)

Fibre	Density, G cm^{-3}	Tensile strength, GPa	Elongation At break, %	Specific tensile strength, GPa*m^3 kg^{-1}	Diameter of elementary fibre, µm
Flax	1.5	1.5	3.0	1.0	20
Hemp	1.5	0.7	3.0	0.5	30
E-glass	2.6	2.4	2.5	0.9	3-30
Aramide High modulus	1.5	3.1	1.0	2.1	12
Carbon High modulus	1.8	2.2	0.5	1.2	8

The acquired long fibres are used in textile industry for spinning into yarn, weaving, knitting and geo-textile production. However, as the long flax fibre is used for manufacturing woven textile materials, the shorter ones are used in nonwoven and technical textile production. In addition, short fibres are used in non-textile markets including packaging of materials, reinforcements for plastics and concrete as alternative for glassfibre, insulation or decorative panels, and lining materials for car industry. The main goal of the current study is to develop new long flax fibre reinforced composite materials for marine and windmill industry applications.

MATERIALS AND METHODS

The aim of the technological tests with flax fibre was the experimental manufacturing of natural fibre composite plate material for cutting tensile test specimens (dog bone shape). In traditional composite products made by hand, using lamination technology with glass fibre, the fibre content in laminate mats is 25 30 wt.%. Hence, our target was to achieve a 20-25 wt% flax fibre content in laminate with thickness 3 mm. The low viscosity (0.5-0.8 PaS) FD epoxy resin was chosen to ensure good wettability properties of flax fibres.

Technological tests with flax fibres (250-300 mm) were conducted according to three different technologies. Firstly, flax fibres were rolled with a radial toothed roller and then combed to divide fibres smoothly and orientate them in one direction. The first lamination tests were carried out by hand lamination with low viscosity FD epoxy resin. The fibres were rolled in a 300x300 mm area, 10 g of fibres per layer. Eight layers were oriented in turn 0° and 90° direction. As flax fibre was sturdy and tough the result of hand lamination was a loose, aerial, soft and flexible material.

For tightening the fibre layers and compression of material, the laminate was consolidated with vacuum bagging technology by using draught pressure -0.8 bar.

After consolidation the laminate resembled felt and was very dry, aerial, loose and flexible, with thickness about 8 mm. The resin content in material was 60 wt.%. It was obvious that vacuum suction had exhausted the resin between the flax fibres. This felt material (see Fig. 2) was not appropriate for tensile tests.

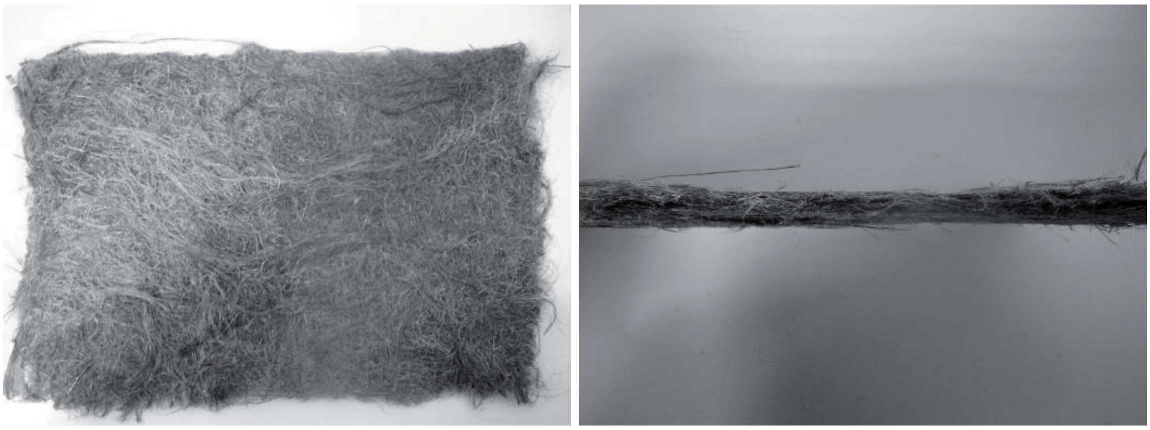
a) b)

Fig. 2. Flax felt plate after vacuum bagging: a) Top view of the material, b) Cross section of the material.

Thirdly, compression moulding technology was used. Two plates 180x180 mm were cut out from the felt and impregnated with FD epoxy resin, after which they were packed in peel-ply fabric and placed between three metal sheets. Between the metal sheets were placed the 3 mm thick edges to assure laminate thickness after compression. Then the metal mould with impregnated flax laminate was placed under press for compression moulding. The press plates were heated up to 30°C to ensure better wettability by reducing epoxy resin viscosity. Metal mould plates were pressed against the edges to achieve the desired 3 mm thickness of the laminates. After one hour the temperature of the press plates was raised to 40°C, and finally, after some period to 50°C. After six hours post curing of the laminate it was cooled down with press plates. The laminate was easily taken out from mould. Flax fibre content in the laminate was 20-25 wt.%. Ten tensile specimens (type 1B) according to standard ISO 527-4 were milled from the laminates.

RESULTS AND DISCUSSION

Tensile test of composite plastic materials was performed according to standard ISO 527-1:2000. The mechanical properties, such as tensile strength, elongation, and modulus of elasticity were determined. Specimens for tensile test were prepared according to ISO 527-2:2000 type 1B. The cross-sections of the specimens were measured with calibrated calliper gauge with measurement accuracy 0.01 mm. The axial extensometer with the gauge length of 50 mm (travel +50% to –10%), was used to measure axial strain in a specimen. The applied testing system was the servo-hydraulic testing machine *Instron* 8800. The tensile tests were performed with loading velocity 2 mm min^{-1}, tolerance ± 20%.

As it follows from Fig. 3, the deformation of the specimens was elastic. As the mechanism of fracture was brittle, from the stress-strain curves, only slight plastic deformation occurred in some tested specimens after elastic deformation before breakage. Flax fibre was broken before pulling it out of the thermosetting resin matrix which means that the strength of the matrix resin was higher than that of fiber. The adhesion between resin matrix and flax fibre was good.

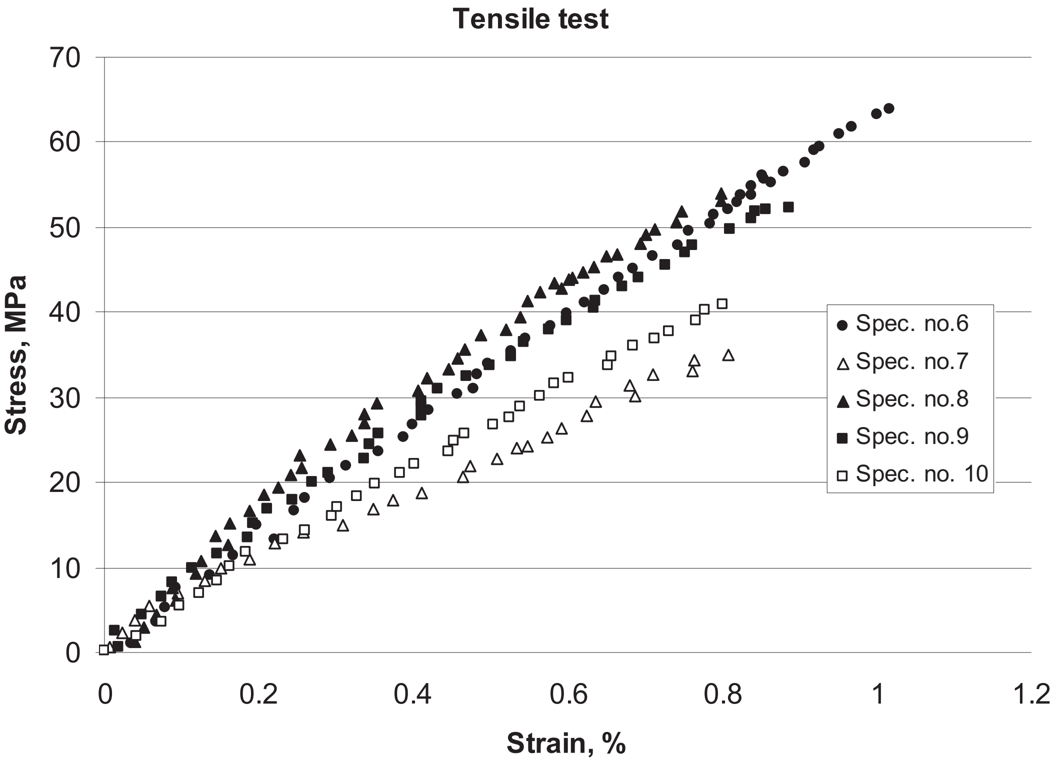

Fig. 3. Stress-strain behaviour of natural fibre composites in tensile test.

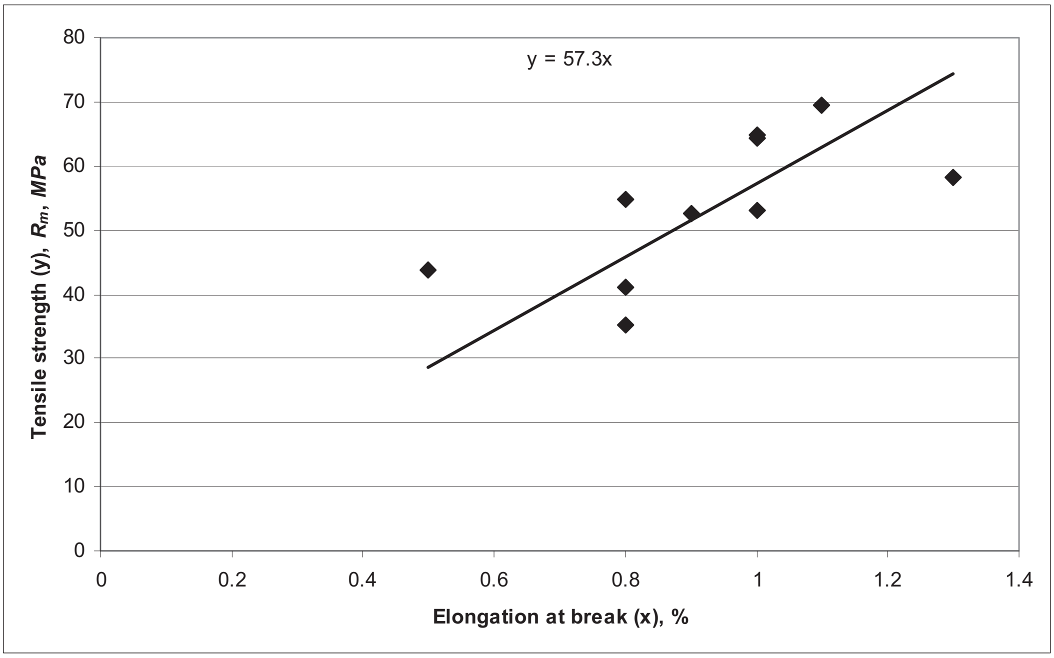

Fig. 4. Tensile strength versus elongation at break.

The dependence of tensile strength on elongation at break is presented in Fig. 4. Mainly elastic deformation occurred and therefore stress-strain behaviour can be prognosticated by linear trend.

According to technical datasheet, the tensile strength of neat resin was 60 MPa. 30% of tested flax fibre composite specimens had better tensile properties than those of neat epoxy resin and 40% of the specimens had 5–10% lower results (see Fig. 4). The tested natural fibre composite specimens are presented in Fig. 5.

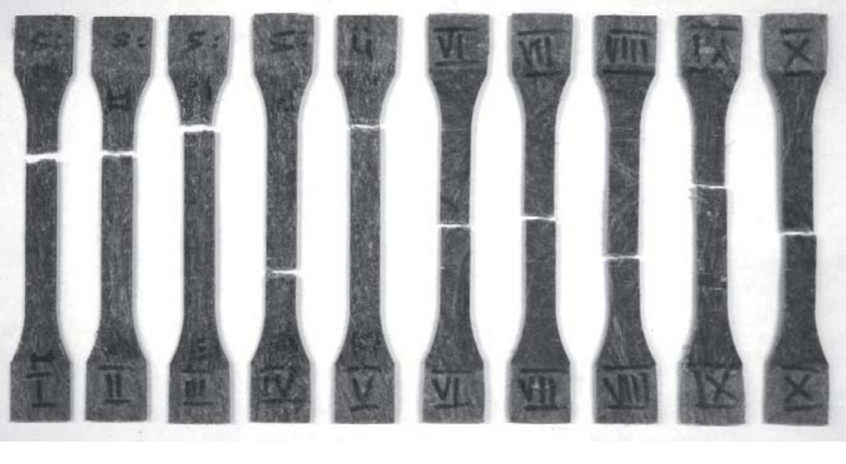

Fig. 5. Breakage of tested tensile specimens

The average elongation at break was 0.9%. According to technical datasheet, the elongation at break for neat FD epoxy resin is 6%. As for flax fibre, elongation at break is 3% (Andersons et al., 2005). This means that elongation at break decreases when epoxy matrix is filled with flax fibres. One of the reasons could be the porosity of the composite material. To study the morphology of flax fibre and epoxy resin matrix with optical microscope, micro polishes of natural fibre composite were made (see Figs. 6-7). As a result of the study it can be concluded that pores at the top surface of the composite affected the tensile test results by forming stress concentrators at the edges of the tensile specimens.

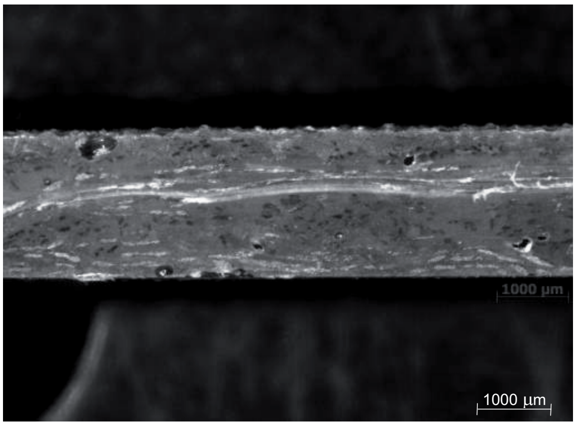

Fig. 6. Cross-section of specimen.

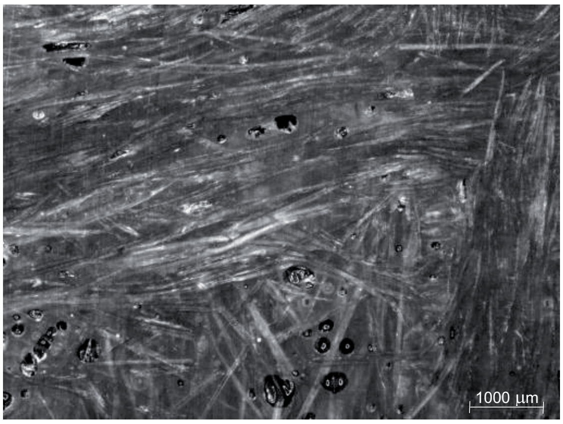

Fig. 7. Top surface of specimen.

These pores could be avoided by using vacuum infusion technique for further experimental manufacturing tests. The suction of the vacuum pump removes air from the composite material. Wettability and surface activation of flax fibre needs further investigation and tests with different matrix resins.

CONCLUSIONS

Short natural fibres are mainly used by automotive industry as reinforcement in injection moulded composites with thermoplastic matrix or sheet moulding compounds with thermosetting matrix.

This work focused on the development of composites with long flax fibre and thermosetting matrix, which are commercially not available on the market. The technological tests with long flax fibre composite manufacturing were successful. The tensile strength of flax fibre reinforced composite was quite similar to neat resin properties. It provides a good basis for the development of new environmentally friendly high performance composite materials.

For further testing, the new flax fibre with better mechanical properties should be used to improve tensile strength and elongation properties. For the manufacturing of bio composites, the availability of suitable bioresins should be considered. The wettability properties and surface activation of flax fibre needs further studying. As flax fibre has lower density than that of glass fibre, it has a good strength density ratio, which makes it a desirable material from the technical, economical and ecological point of view. Long flax fibre reinforced composite material will have application in marine and windmill industry, where a good strength and weight ratio is required.

REFERENCES

Andersons, J., Sparninš, E., Joffe, R., Wallström, L. 2005. Strength distribution of elementary flax fibres. *Composite Science and Technology*. **65**, 3-4, 693-702.

Bos, H. L. Müssig, J. van den Oever, M. J. A. 2006. Mechanical properties of short-flax-fibre reinforced compounds, *Composites Part A,* 37, 10, 1591–1604.

Dweib, M. A., Hu, B. O`Donnell, A. Shenton, H. W., Wool, R. P. 2004, Bio-based composite roof structure: Manufacturing and processing issues. *Composite Structures*. **63**, 147-157.

Foulk, J. A., Akin. D. E. and Dodd, R. B. 2008. Influence of pectinolytic enzymes on retting effectiveness and resultant fiber properties. BioResources 3(1), 155–169.

Frank, R. 2005. Bast and other plant fibres. Cambridge, woodhead Publishing Limited. 432 pp.

Hagstrand, P. O., Oksman, K. 2004. Mechanical properties and morphology of flax fiber reinforced melamine-formaldehyde composites, *Polymer Composites,* **22**, 4, 568 – 578.

Mohanty, A. K., Misra, M., Drzal, L. T. 2005. *Natural Fibres, Biopolymers and Biocomposites*. CRC Press, Michigan, 896 pp.

Muir, A. D. Westcot, N. D. 2003. *Flax: The Genus Linum.* Taylor & Francis Inc. London, 307 pp.

Soiela, M., Ilves, A. and Viikna, A. 2005. Properties of Flax Fiber-Reinforced Polyethylene Films. *Cheminë technologija*, **36**(2), 38-45.

Soiela, M.; Viikna, A. 2003. Properties and use of industrial needlepunched textiles based on short flax fibres. *Agroindustria*, 2(2/3), 99-102.

Zhang, J., Henriksson, G. and Johansson, G. 2000. Polygalacturonase is the key component in enzymatic retting of flax. *Journal of Biotechnology*, **81**, 85–89.