

Development of the technology of preliminary processing of flax plant, long and short fiber extraction in the territory of Fergana region

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Abstract: Contemporary researchers have specified that natural flax fiber is comparable with synthetic fibers due to its unique physical and mechanical characteristics which have been recognized for decades. Flax fiber-reinforced composites have the potential for wide usage in sport and maritime industries, and as automotive accessories. In addition, this composite is in the development stages for future applications in the aeronautical industry. However, designing the flax composite parts is a challenging task due to the great variability in fiber properties. This is caused by many factors, including the plant origin and growth conditions, plant age, location in the stem, fibers extraction method, and the fact that there is often a non-uniform cross section of the fibers. Furthermore, the water and moisture absorption tendency of the flax fibers and their composites and the consequent detrimental effects on their mechanical performance are also major drawbacks. Fibers may soften and swell with absorbed water molecules, which could affect the performance of this bio-composite. Flax fibers' moisture absorption propensity may lead to a deterioration of the fiber–matrix interface, weakening the interfacial strength and ultimately degrading the quality of the composite. This review represents a brief summary of the main findings of research into flax fiber reinforced composites, focusing on the challenges of its water and moisture absorption behavior on their performance.

Keywords: Flax fiber composites, moisture absorption, mechanical properties, interfacial strength, water diffusion

Structure and composition of flax fiber.

A flax stem has the constituents of bark, phloem, xylem, and a void at the center. The fibers are located as fiber bundles in the outer surface of the plant stem as shown in Figure 2. The flax plants can grow to heights of 80 to 150 cm in less than 110 days since the plants are fast-growing by nature. The bundles (technical fibers) are between 60 and 140 cm long and their diameter ranges from 40 to 80 μ m. A flax stem contains 20–50 bundles in its cross section. Each bundle consists of

10–40 spindle-shaped single (elementary) fibers 1–12 cm long and 15–30 μm in diameter. Charlet et al reported that the elementary fiber diameters are different if taken from the bottom, the middle, and the top part of the flax stems. The mean fiber diameter was found to decrease from the bottom to the top of the stems.

The elementary fiber (Figure 3) denotes a single cell in the flax plant. Each elementary fiber is composed of concentric cell walls that are different from each other in terms of thickness and the arrangement of their constituents. Each cell wall consists of what is known as a primary (outer) and a secondary cell wall. These are concentric cylinders with a small open channel in the middle called a lumen. The primary cell wall can be up to 0.2 μm thick and the lumen can be as small as 1.5% of the fiber cross section. The secondary cell wall contains three sub-layers S_1 , S_2 , S_3 . The single flax fibers have been shown to possess different shapes within cross sections along the fiber axis, which some researchers approximated to hexagonal or pentagonal cross sections. However, the fibers vary in their non-uniform geometrical shapes along the axis. Owing to these irregularities in the thickness of the cell walls, the fibers vary greatly in strength.

The main constituents of flax fibers are cellulose, hemicellulose, lignin, and pectin. A small percentage of wax, oil, and structural water are also found. Both primary and secondary cell walls are composed of cellulosic materials. Cellulose fibrils (diameter between 0.1 μm and 0.3 μm) are surrounded by concentric lamella, composed of about 2% pectin and 15% hemicellulose, which contribute to the thermal degradation and water uptake behavior of the fibers. The secondary cell wall is the major part of the fiber diameter and S_2 layer is its dominating constituent. This layer consists of highly crystalline cellulose microfibrils bounded by lignin and hemicellulose. The microfibrils in the S_2 layer follow a spiral pattern at an angle of 5–10° along the fiber axis, which explains the stiffness and strength of the fiber in the axial direction. The middle lamella is considered to be the matrix which bonds the cell together described the technical fibers, which are extracted by partially separating the fiber bundles in the flax plant and can be as long as the stem length (approximately 1 m). The technical fibers (i.e. the bundles of elementary fibers) consist of 10–40 elementary fibers in the cross section. The elementary fibers overlap for a considerable length and are glued

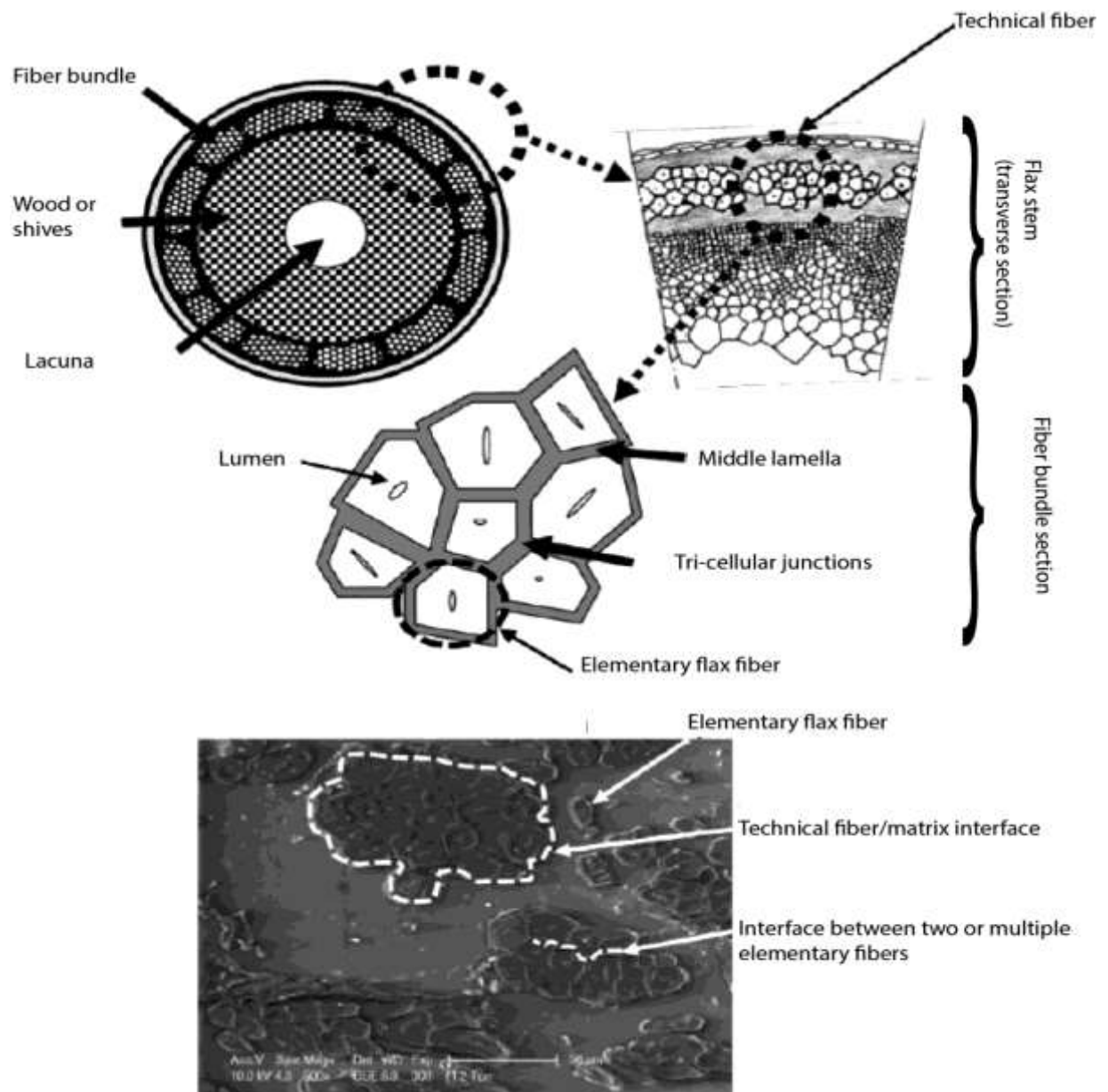


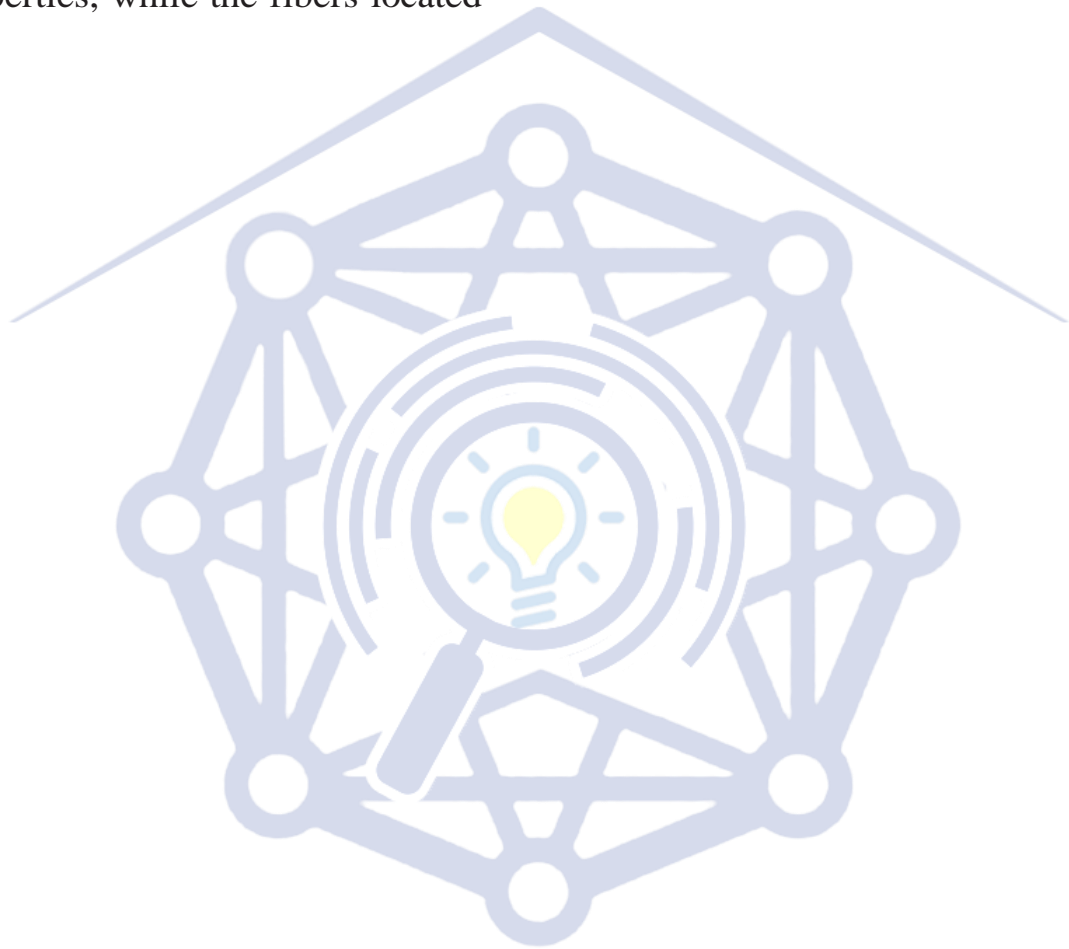
Figure 1. Structure of the flax fiber: (a) cross section of flax plant stem and position of the bundles of elementary fibers and technical fibers after extraction, (b) SEM image of a technical fiber with its constituting elementary fibers.

Factors affecting the properties of flax fibers

Flax is investigated at the elementary and technical fiber level. The great variability reported for flax fiber properties (tensile strength and modulus of elasticity, among others) is a consequence of many factors, including plant origin



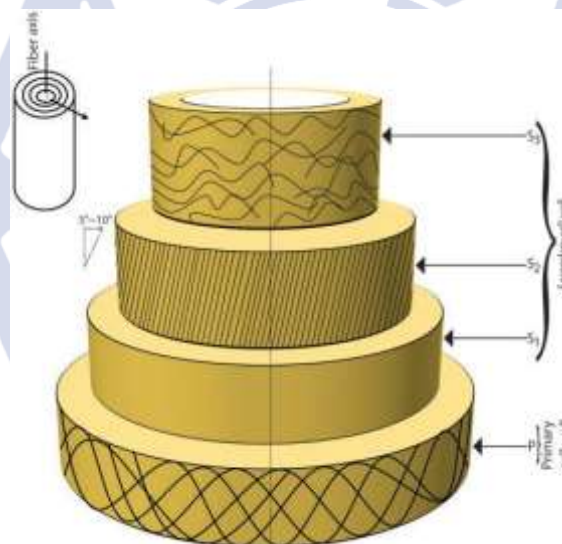
and growth conditions, plant age, location in the stem, and a non-uniform cross section of all the fibers. Due to this inherent variability, a Weibull distribution function was used to describe the tensile strength of the flax fibers found that mechanical properties of flax fibers were influenced by the location in the stem. Flax fibers located at the bottom of the stem display the poorest mechanical properties, while the fibers located



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in the middle are the ones that show the best mechanical performance. The biochemical analysis confirmed that both cellulose and non-cellulosic polymers are to be found prolifically in most extensive contents of the middle fibers. Cellulose is considered as the equivalent reinforcing material of a composite structure, whereas non-cellulosic materials are the matrix constituent that supports the exchange of load from one microfibril to another. Bos et al.²⁷ reported that the technical fiber strength decreases when the clamping length increases because of the similar composite-like structure of this fiber. They performed tensile tests to determine the strength of elementary and technical flax fibers and found that elementary flax fibers showed a considerably higher strength than technical fibers of the same length due to a bundling effect. During testing of the technical fiber bundle,



it was found that all elementary fibers are not firmly bonded with the matrix

Figure 2. An elementary fiber structure.

constituents, which happens especially in the secondary cell wall region. As a result, less-efficient stress transfer was found in the tensile tests, producing reduced strength as compared to elementary fibers. These results are quite consistent with that.

Fiber extraction methods also influence the mechanical properties of the flax fibers. Bos et al.²⁷ revealed that the tensile strength of the fibers is



dependent on the isolation procedure, with manually isolated fibers being stronger than mechanically isolated ones. The mechanical processes of fiber extraction were found to induce kink bands in the fibers, thus reducing their tensile strength. However, they noted that the scatter in strength is much larger for the elementary fibers isolated by hand than for the standard mechanically isolated ones. They claimed that the mechanical fiber processing methods generate a number of large defects, which reduces the scatter in the fiber strength, although the fibers show a lower mean strength. In a different study³⁸ of elementary flax fiber tensile tests, it was found that fibers separated by enzyme treatment may receive less damage than those by mechanical processes introduced a new method of fiber extraction from 35% aqueous ammonia pre-treated flax stems, comparing this with a standard extraction process. They found both tensile and flexural properties of flax fibers were increased due to the ammonia treatment. The average tensile strength of ammonia-treated fibers was almost 50% higher than the one obtained with the commercial extraction processes. In addition, higher flexural toughness was also evident for the ammonia-treated fibers.

The tensile strength of the elementary flax fibers was tested who found that fiber kink bands and micro-compression defects were the main cause of strength reduction. These two defects act as points of fracture initiation during fiber failure. Both the tensile strength and Young's modulus decreased when the fiber diameter was increased, with associated fiber

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Table 1. Bast fibers: compositions, physical and mechanical properties

Bast fibers	Compositions (%)						Density (gm/cc)	Young's modulus (GPa)	Tensile strength (MPa)	Elongation at break (%)
	Cellulose	Hemicellulose	Lignin	Pectin	Wax	Other				
Flax	60–81	14–20.6	2–3	1.8–5	1.7	1.5	27.6	345–1500	2.7–3.2	
Hemp	70–92	17.9–22.4	3–5.7	0.9	0.8	1.4–1.5	17–70	368–800	1.6–4	
Jute	51–84	12–20.4	5–13	0.2	0.5	1.3–1.4	10–30	393–773	1.2–1.5	
Kenaf	31–57	13.6–21	5.9–19	2	–	1.2	14–53	240–930	1.6	
Ramie	68.6–76.2	13–16.7	0.6–1	1.9–2	–	1.5–1.56	27–128	400–1000	1.2–3.8	
Banana	60–65	6–19	5–10	3–5	–	1.3–1.35	27–32	529–914	1–3	

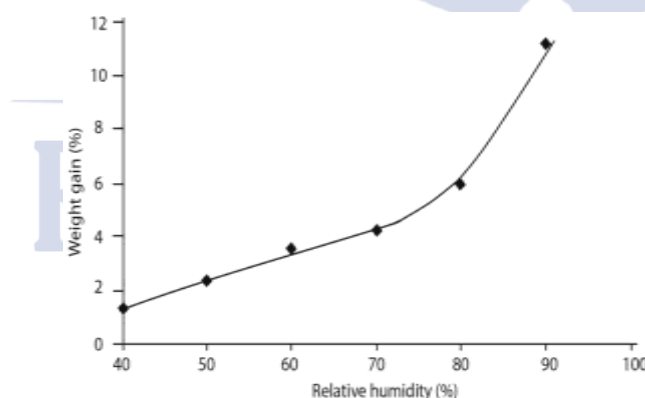


Figure 3. Effect of fiber diameter on fiber strength

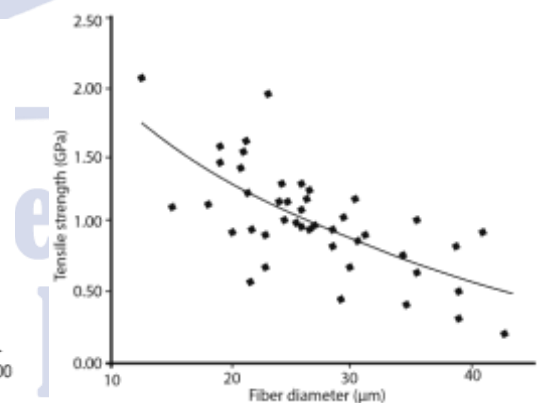


Figure 4. Equilibrium different RH.



Fiber conditions and humidity	Matrix used	Diffusion coefficient, D (cm ² /s)	Manufacturing methods and other conditions Reference
UD and twill fibers at 55°C and 75% RH	UP	0.00104 × 10 ⁻³ 0.02	Hand lay-up, 8.89% water uptake 73
Green flax	PP	1.3 × 10 ⁻²	for UD flax composites and 10.24% uptake for twill flax composites Moisture uptake reduced by 30% 45
Treated flax	PP	7.8 × 10 ⁻³	in treated flax composites
Treated flax Flax at 23°C, 80% RH	MAPP	5.0 × 10 ⁻³ 0.002 × 10 ⁻³	(duration 14 days) Extrusion 74
Flax at 25°C, maximum immersion 40 days	Bio epoxy	37.1	Hand lay-up, Equilibrium moisture content, 9.61% 70
Flax at three orientations (0°, 45°, 90°), immersion at room temperature	Epoxy	6.67 × 10 ⁻⁹ for 0°	Press platen process, maximum moisture uptake 68
0°/90° flax at 40 and 55 wt%, immersion at room temperature, 32 days immersion test	Bio-epoxy	12.45 × 10 ⁻⁹ for 45° 14.19 × 10 ⁻⁹ for 90° 1.63 × 10 ⁻⁸ for 40% 2.32 × 10 ⁻⁸ for 55%	moisture uptake 13.70% by 45° fiber orientation RTM, Saturation water absorption 8.71% and 6.23% by 55% and 40% fiber volume, 75
Twill flax, immersion at room	Acrylic	7.7 × 10 ⁻⁹ 0.03	respectively Vacuum infusion, moisture at 69



temperature	Epoxy	8.1×10^{-9} 0.04	equilibrium, 6.6% for flax- acrylic and 7.31% for flax- epoxy composites
Flax fiber bundles, immersion	PP	2.23×10^9	Compounding, saturated mois- 76
test at room temperature	MAPP	0.92×10^9	ture content, 9.09% for flax-PP and 8.53% for flax- MAPP composites
(212 days), 40% fiber volume			

Table 3. Diffusion coefficients of flax fiber composites according to literature.

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