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Productivity and Tensile Endurance Determination of Hemp Fiber

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The yield of hemp dry matter in Latvia's agro-climatic conditions depending on the variety accounted for an average of 7.4 - 12.4 t ha^{-1}. Dependence on the version being subject to inspection, the yield of dry matter for variety 'Futura' was 11.0 to 12.4 t ha^{-1}, 'Bialobrzeskie' - 9.5 to 10.7 t ha^{-1}, but for 'Tygra' - 7.4 to 8.7 t ha^{-1}, and the total fiber yield - respectively 3.15, 2.65 and 2.40 t ha^{-1}.Three industrial hemp varieties 'Bialobrzeskie', 'Futura75' and 'Tygra' were tested for natural hemp fiber (with splint) tensile strength. Samples to be measured were selected and sized in 50 mm long pieces of fibers, for each thickness was measured in three places and its average value was calculated. In order to secure the samples in the test machine, a previously elaborated method was used ensuring convenient fixing and correct disruption of the sample. Results of the experiments were indicative of the cutoff stress of tensile strength for non-blanched fiber of three varieties of hemp with bast addition. The 'Tygra' variety of fibers is having the greatest resistance. Their average tensile strength amounted to 558 MPa, which is equivalent to the tensile strength of high quality steel. It should be noted that the experiments have established a large distribution of the measurement results. The tensile strength of individual samples ranged from 715 MPa to 373 MPa. This is explained by the fact that hemp fiber is a non-homogeneous material, and its properties are varied within wide limits. It should be noted that tensile strength of fiber of all the varieties is large enough to allow it to be used for reinforcement of foam gypsum. The aim of this study was to evaluate hemp (*Cannabis sativa* L.) as a building material resource.

1. Introduction

Industrial hemp (*Cannabis sativa* L.) is one of the earliest domesticated and most versatiled plants known to people. It has been cultivated over of many centuries in many regions of Europe and of the World.
Latvian climate is suitable for the hemp fiber production. Hemp fibres are used in a wide range of products, including fabrics and textiles, yarns and raw or processed spun fibres, paper, carpeting, home furnishings, construction and insulation materials, auto parts, and composites. In recent years, there is a growing interest for the use of natural materials in composite applications, where cellulose materials are reinforced in gypsum matrix. A result is environmentally friendly low density building material, which can show high tensile and compressive strength, good heat and sound insulation properties. Foam gypsum is produced using gyps cohesive substance, manufacture of which is environmentally friendly and energy efficient (Skujans et al., 2007). A new energy saving composite building material – foam gypsum with fibrous hemp reinforcement is investigated in Latvia University of Agriculture (Brencis et al., 2011). The foam gypsum was produced using the dry mineralization method mixing water, gypsum, surface active stuff (SAS), and adding hemp's reinforcement. Fibre particle length used for foam gypsum reinforcement varies between 5 and 20 mm. Hemp fibres are natural fibres and their properties vary according to the plant growing regional climatic conditions, fertilizers, plant density, harvesting time and pre-treatment technological processes.
The analysis of hemp cultivation and use trends in the world and Europe, as well as taking into account the experimental results, we conclude that hemp cultivation and processing in Latvia have good perspectives. Latvian hemp sowing volumes are registered only in year 2008 and in year 2009 was grown 250 ha. In

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recent years, the amount of industrial hemp growers and cultivated areas has increased in Latvia and, according, to data provided by Association of Industrial Hemp of Latvia, plantations area of hemps is 600 ha in 2012.

There are two basic types of fibers: natural fibers and synthetic fibers. Many researchers have studied composites based on these fibers (Skujans et al., 2010) Compared with synthetic fibers, the advantages of using natural fibers in composites are their low cost, low density, unlimited availability, biodegradability, renewability, and recyceability (Mwaikambo and Ansell, 2003). Some studies suggest that natural fibers have the potential to replace glass fibers in polymer composite materials (Kara et. al., 2012).

Natural hemp fibers increase scientific interest in applications of construction elements what can be described by the good mechanical properties exhibited by these natural fibers. Natural fibers can be feasibly used as a component of composite construction materials (Madsen et. al., 2007).

Natural fibres, such as flax, hemp have received considerable attention as an environmentally friendly alternative for the use of glass fibres in engineering composites (Meijer et. al., 1995).These plant fibres have a number of techno-ecological advantages over traditional glass fibres since they are renewable, can be incinerated with energy recovery, show less concern with safety and health (e.g. skin irritation) and give less abrasive wear to processing equipment such as extruders and moulds. In addition, they exhibit excellent mechanical properties, especially when their low density (1.4 g/cm^3 versus 2.5 g/cm^3 of glass) and price are taken into account (Sankari, 2000). Although natural fibres have a number of ecological advantages over glass fibres they also possess a number of disadvantages, such as lower impact strength, higher moisture absorption which brings about dimensional changes thus leading to micro-cracking, as well as poor thermal stability, which may also lead to thermal degradation during processing The fiber quality is determined by the chemical and physical properties (Baltiņa et. al., 2009). Fiber quality reatly is affected by its chemical composition (Jankauskiene and Gruzdeviene, 2009).

Hemp fibres increase the bending strength of foam gypsum (Brencis, 2011). The foam gypsum pore structure has influence on the material volume density and its physical and mechanical properties (Skujans et al., 2010).

2. Materials and methods

The field trials were carried out in 2011-2012 in Research and Study farm “Peterlauki” of the Latvia University of Agriculture. The hemp varieties ‘Bialobrzeskie’, ‘Futura75’ and ‘Tygra’ were sown in the sod calcareous soils (pH$_{KCl}$ 6.7, containing available P 52 mg kg $^{-1}$, K 128 mg kg $^{-1}$, organic matter content 21 to 25 g kg $^{-1}$ in the soil. The total seeding rate was 50 kg ha^{-1}. The plots were fertilised as follows: N-120, P_2O_5- 90, K_2O- 150 kg ha^{-1}. Hemp sowing was made by *Wintersteiger* plot sowing machine in the middle of May in the plots of 10 m^2, triplicate. Hemp was harvested by *a* small mower *MF-70* when the first matured seed appeared (Figure1).

Figure 1: Hemp mowing – a small mower MF-70

Figure 2: Hemp fiber bundle samples

The biometrical indices of the hemp plants, height and stalk diameter in the middle of the stalk at harvesting time, the amount of green and dry over ground mass, and fibre content were evaluated. The means are presented with their LSD test.

Three varieties 'Bialobrzeskie', 'Futura75' and 'Tygra' were tested for natural hemp fiber (with splint) tensile strength. In this research, fiber bundles (Figure 2) were used, because it was difficult to separate single bundles of hemp (Ochi et al. 2002). Samples to be measured were selected and sized in 50 mm long pieces of fibers, for each sample thickness was measured in three places and its average value was calculated. Measurements were taken with digital sliding calipers with the digital measurement error

±10 μm. In order to secure the samples in the test machine a previously elaborated method was used ensuring convenient fixing and correct disruption of the sample (Figure 3). Samples were fixed in a cardboard frame with external size of 50 mm. Ends of the sample were stuck to the cardboard by gluing in its ends between the cardboard pieces. After fastening of a sample in the frame, measurements of its width were taken using digital microscope Keyence VHX - 300.

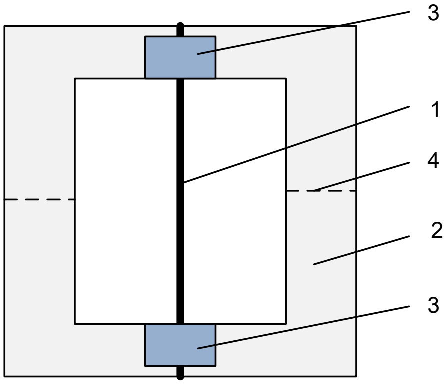

Figure 3: Fiber sample fixing in the cardboard frame before testing
1- fibre sample, 2 –cardboard frame,3 - strengthen cardboard, 4 - a cut place

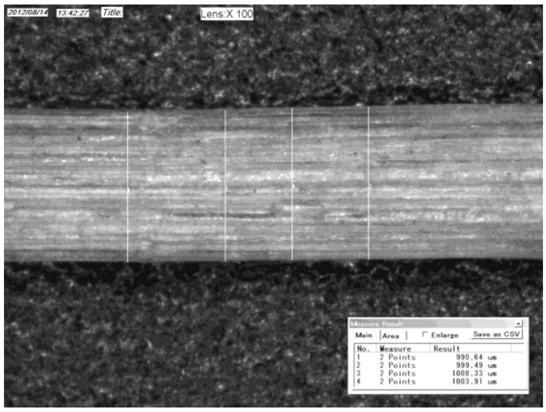

Figure 4: Fiber sample width measurement with a digital microscope Keyence VHX - 300

Width of the sample was measured at least in three places and the average value was calculated (Figure 4). To determine maximum disruption force for the sample, it was loaded under tension by using material testing machine Zwick 2500. The sample was placed in the machinery fastenings, by compressing the parts glued in the sample cardboards. After fastening, the cardboard frame is cut on both sides (place of cutting 4, Figure 1). Then loading of a sample was performed and the tensile chart was shot, from which the maximum disruption force was defined. The rupture stress and the tensile strength of the fiber was calculated using software Test Expert.

3. Results and discussion

Field trials have established that the yield of hemp dry matter in Latvia's agro-climatic conditions depending on the variety accounted for an average of 7.4 - 12.4 t ha^{-1}. Dependence on the version being subject to inspection, the yield of dry matter for variety 'Futura' was 11.0 to 12.4 t ha^{-1}, 'Bialobrzeskie' - 9.5 to 10.7 t ha-^{1}, but for 'Tygra' - 7.4 to 8.7 t ha^{-1}, and the total fiber yield - respectively 3.15, 2.65 and 2.40 t ha^{-1}.

The cultivation year and the selected variety had significant effect on the hemp yield (Table 1). Hemp variety ‘Futura 75’ was the most productive. The yield is an important result of genetic and environmental interaction, and it is used as one of criteria for determination of the genotype response on specific agro-ecological conditions (Murphy et al., 2007).

Table 1: The hemp productivity indicators in Latvia

Hemp varieties	Dry matter, t ha^{-1}		Fiber yield, t ha^{-1}		Plant height, m	
	2011	2012	2011	2012	2011	2012
‘Futura 75’	12.4	11.0	3.60	2.70	3.27	3.03
‘Bialobrzeskie’	10.7	9.5	2.86	2.44	2.94	2.77
‘Tygra’	8.7	7.4	2,57	2.23	2.69	2.48
Average	10.7	9.3	3.01	2.46	2.97	2.76
LSD_{05year}	0.94		0.14		0.11	
$LSD_{05variety}$	1.43		0.26		0.19	
$LSD_{05interactions\ between\ year\ and\ variety}$	2.84		0.37		0.23	

The tensile strength of the 2011 and 2012 hemp fiber harvest was determined and compared. Results of the experiment were indicative of the cutoff stress of tensile strength for non-blanched fibre of three varieties of hemp with bast addition. Tensile test results were obtained with hemp fiber rupture curves of several samples, Figure 3. With each species, samples were taken at least 30 repetitions. It should be noted that the experiments have established a large distribution of the measurement results. The tensile strength of individual samples ranged from 715 MPa to 273 MPa. This is explained by the fact that hemp fiber is a non-homogeneous material, and its properties are varied within wide limits. Some samples showed a very high tensile strength in excess of 1000 MPa. Samples with very high and very low tensile strength was evaluated as gross measurement error and excluded from the calculation.

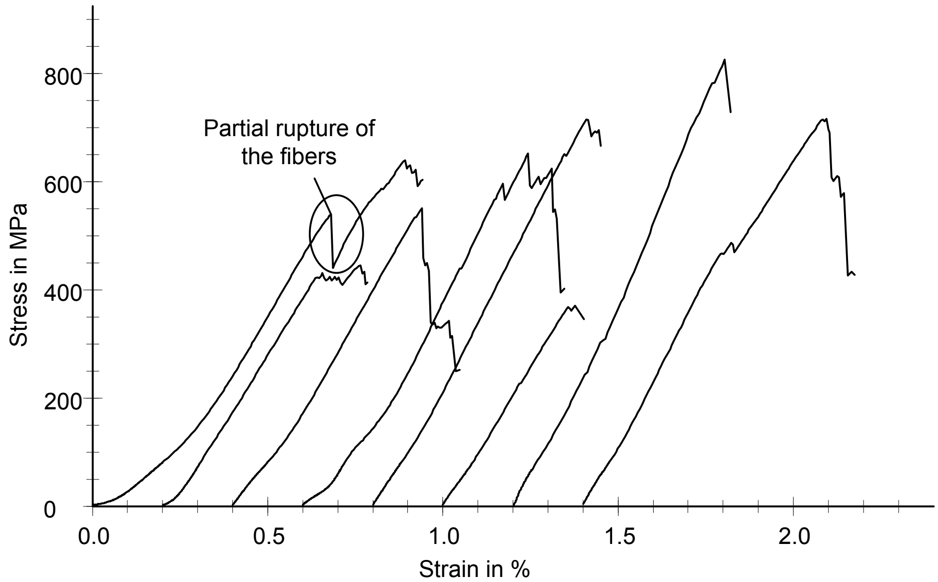

Figure 5: Hemp fiber specimen rupture curves for different samples of the hemp variety Tygra

Some samples were observed partial rupture of the fibers, which can be explained by the uneven fiber strain during loading (Figure 5).

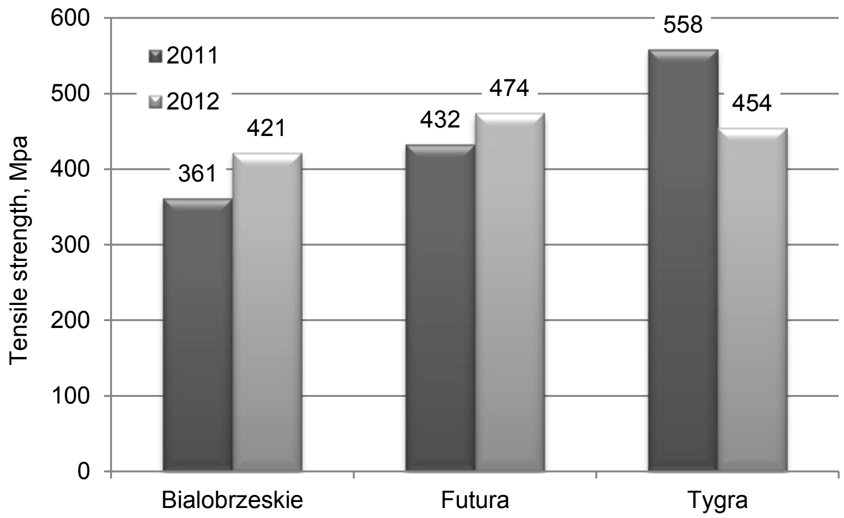

Figure 6: Tensile strength of hemp fiber depending on hemp varieties

After the experiment data processing, the average tensile strength of the two-year yield of three varieties of hemp was established. 2011-th year's crop variety Tygra showed the highest average tensile strength (Figure 6). Their average tensile strength amounted to 558 MPa, which is equivalent to the tensile strength

of high quality steel. 2012-th the tensile strength of this variety was 454 MPa, which is approximately equal to the variety Futura tensile strength.
Fiber tensile strength of the hemp variety Bialobrzeskie was 361MPa (harvest 2011) and 421MPa (harvest 2012). Hemp variety Bialobrezskie in both years showed an average of 14 % less tensile strength than the variety Futura and 23 % less than the variety Tygra.
The modulus of elasticity was determined for all fiber samples (Figure 7). Greatest modulus of elasticity E=37.9GPa was stated for the variety Tygra (harvest 2012), smallest E=18.6GPa for the variety Bialobrzeskie, harvested in 2012. Large data dispersion during experiments was determined for hemp fiber samples. Modulus of elasticity of the hemp variety Tygra lies between 31 and 44GPa.

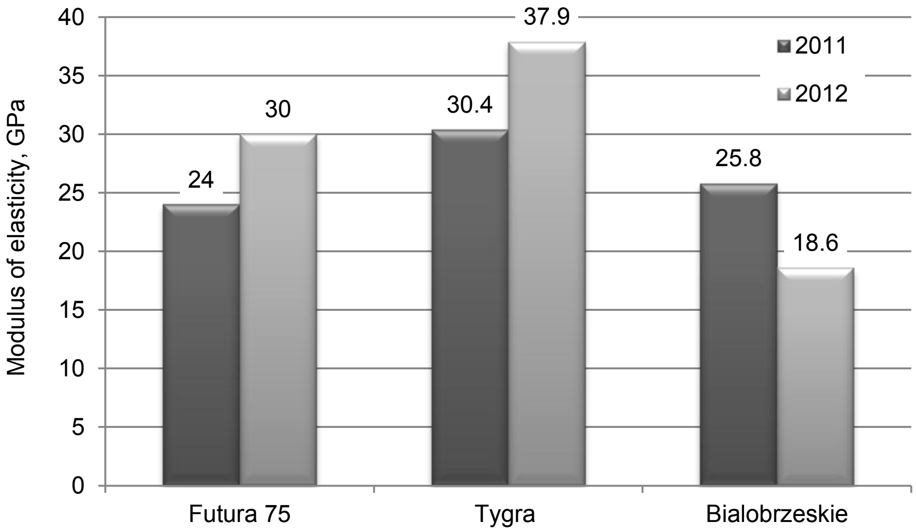

Figure 7: Modulus of elasticity for different varieties of the Hemp

Modulus of elasticity correlates with the tensile strength of hemp fibers. Average modulus of elasticity and tensile strength was calculated for the all samples of the hemp harvested in both years.

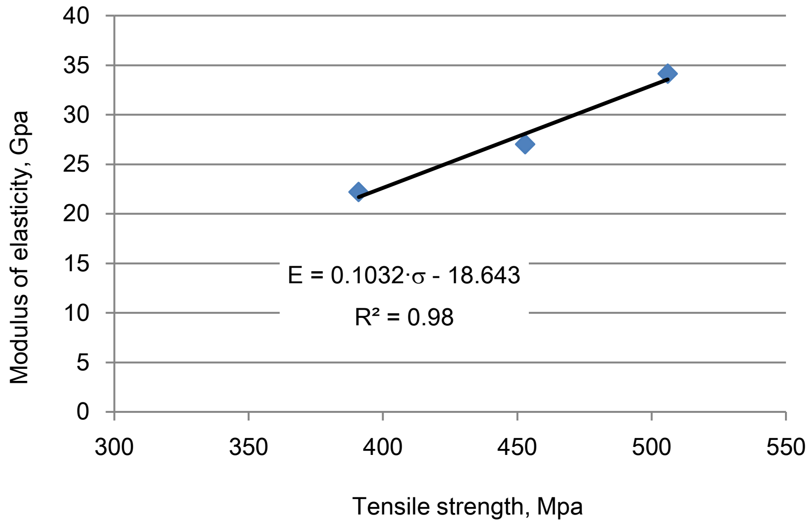

Figure 8: Modulus of elasticity depending on the tensile strength

It was found that the modulus of elasticity depends on the tensile strength (Figure 8). Correlation between modulus of elasticity and tensile strength of different hemp varieties are linear, the coefficient of determination R^2 = 0.97.

The results obtained suggest that the hemp fiber tensile strength is similar to steel, tensile strength, and modulus of elasticity is significantly smaller. This means that hemp fiber is more flexible than steel and allows for greater deformations. It should be concluded that the hemp fiber tensile strength of all varieties is large enough to allow it to be used for the foam gypsum reinforcement.

4. Conclusions

1. The greatest total fiber yield 3.15 t ha^{-1} was stated for variety “Futura”, but lowest – 2.40 t ha^{-1} for variety “Tygra”.
2. The greatest tensile strength 558 MPa was stated for variety “Tygra” (2011), but hemp harvested in 2012 gave tensile strength 454 MPa similar to variety Futura.
3. Hemp variety Bialobrezskie in both years showed an average of 14 % less tensile strength than the variety Futura and 23 % less than the variety Tygra.
4. The hemp variety Tygra fibre had the greatest modulus of elasticity in both harvesting years. It varies from 30.4 to 37.9 GPa.
5. All the tested fiber tensile strength is similar to the tensile strength of steel and is recommended foam gypsum reinforcement.

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