EVALUATION OF HEMP STRAW AND FIBRE STRENGTH

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Abstract. In recent years, there is a growing interest for the use of natural materials in composite applications, where cellulose materials are reinforced in foam 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. Hemp (*Cannabis sativa* L.) 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 objective of the present research was to evaluate hemp straw and fibre strength to use them for gypsum reinforcement. Hemp straw compressive strength of longitudinal and transverse stresses compressing the samples between two parallel planes was established. The results show that the variety 'Bialobrzeskie' longitudinal compressive strength is 19.5 MPa on average, but the transversal strength of 1.33 MPa. Variety 'Futura 75' shoved longitudinal compressive strength 23.1 MPa, while the transverse strength is 1.32 MPa and variety 'Santhica 27' showed the values 26.4 MPa and 1.55 MPa. The hemp varieties that are suitable for reinforcement of foam gypsum fiber tensile strength were determined. The tensile strength of individual samples ranged from 273 MPa to 715 MPa.

Keywords: hemp fibre, hemp straw, tensile strength, modulus of elasticity.

Introduction

Industrial hemp (*Cannabis sativa L.*) is one of the earliest domesticated and most versatiled plants known to people. It has been cultivated over 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 [1]. A new energy saving composite building material – foam gypsum with fibrous hemp reinforcement is investigated at the Latvia University of Agriculture [2]. The foam gypsum was produced using the dry mineralization method mixing water, gypsum, surface active stuff (SAS), and adding hemp reinforcement. The 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. Analysing 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.

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. Natural fibres, such as flax, hemp have received considerable attention as an environmentally friendly alternative for the use of glass fibres in composite materials [3; 4]. 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 the processing equipment such as extruders and moulds. In addition, they exhibit excellent mechanical properties, especially when their low density (1.4 $g \cdot cm^{-3}$ versus 2.5 $g \cdot cm^{-3}$ of glass) and price are taken into account [5; 6]. 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 fibre quality is determined by the chemical and physical properties. Hemp fibres increase the bending strength of foam gypsum [2].

The objective of the present research was to evaluate hemp straw and fibre strength to use them for gypsum reinforcement.

Materials and methods

Six varieties of hemp harvested in years 2011 and 2012 were tested for natural hemp fibre (with splint) tensile strength. In this research, fibre bundles were used, because it was difficult to separate single fibres of hemp. Hemp fibre was air dried to the humidity less than 10 %. Samples to be measured were selected and sized in 50 mm long pieces of fibres, for each sample thickness was measured in three places and its average value was calculated. The measurements were taken with digital sliding callipers 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 (Fig. 1). The samples were fixed in a cardboard frame with the external size of 50 mm. The 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.

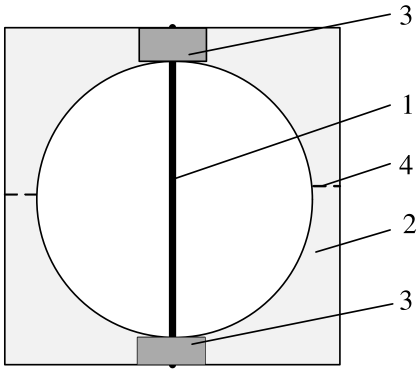

Fig. 1 **Fibre sample fixing in the cardboard frame before testing:** 1 – fibre sample; 2 – cardboard frame; 3 – strengthen cardboard; 4 – a cut place

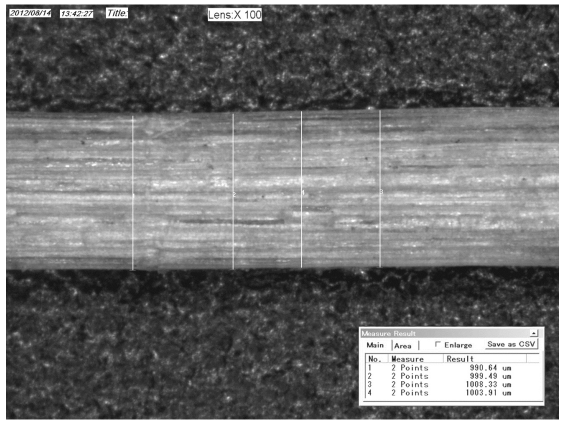

Fig. 2 **Fibre sample width measurement with a digital microscope Keyence VHX – 300**

Width of the sample was measured at least in three places and the average value was calculated (Fig. 2). To determine the maximum breaking force for the sample, it was loaded under tension by using the 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, Fig. 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 fibre were calculated using the software Test Expert.

The modulus of elasticity of the material describes its deformation, depending on the tensile strength and it is essential for obtaining a high-quality product. During the tensile strength test the computer software Test Expert simultaneously carries calculation of the modulus of elasticity. In this way values of the modulus of elasticity for each sample were obtained.

To determine the hemp stalk compressive strength, 20 mm long samples were prepared. Using Keyence microscope the stem outer and inner diameters were measured and the cross section was calculated. Compressive strength was determined compressing the samples between two parallel planes in transverse and longitudinal directions using the testing machine Zwick2500.

The foam gypsum was produced using the dry mineralization method mixing water, gypsum, surface active stuff (SAS), and adding hemp reinforcement [2]. This means that the hemp fibres are soaked in water [2]. To find hemp fibre strength variation experiments were made with wet fiber. The sample prior to mounting the testing machine was saturated with water for 2 minutes. The tensile test was carried out immediately after soaking.

Results and discussion

The 2011th and 2012th harvest hemp fibre tensile strength was determined and compared. The results of the experiment were indicative of the cutoff stress of tensile strength for non-blanched fibre of six varieties of hemp with best addition. Tensile test results were obtained with hemp fiber rupture curves of several samples, Fig. 3. With each variety samples were taken at least 30 repetitions. It should be noted that the experiments have established a large dispersion 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 fibre 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. The samples with very high and very low tensile strength were evaluated as gross measurement error and excluded from the calculation.

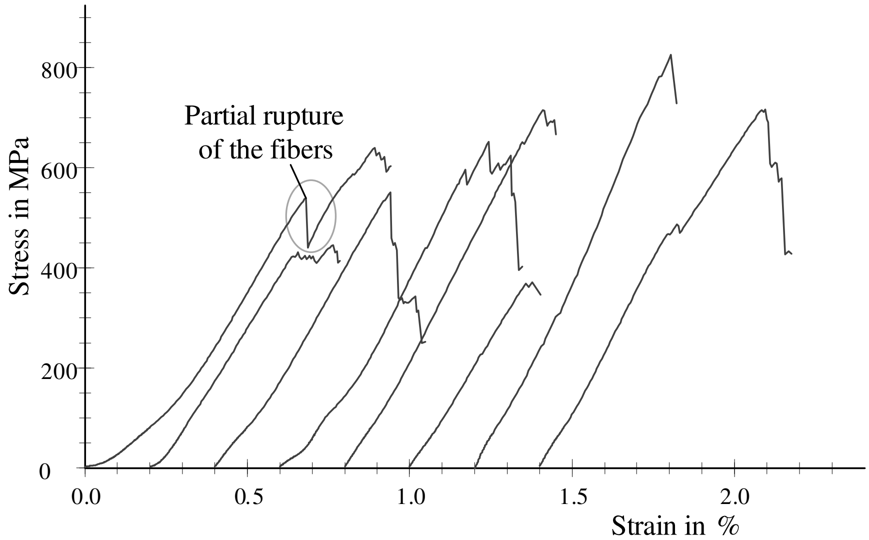

Fig. 3. **Hemp fiber specimen rupture curves for different samples of the hemp variety Tygra**

In some samples partial rupture of the fibres was observed, which can be explained by the uneven fiber strain during loading (Fig. 3).

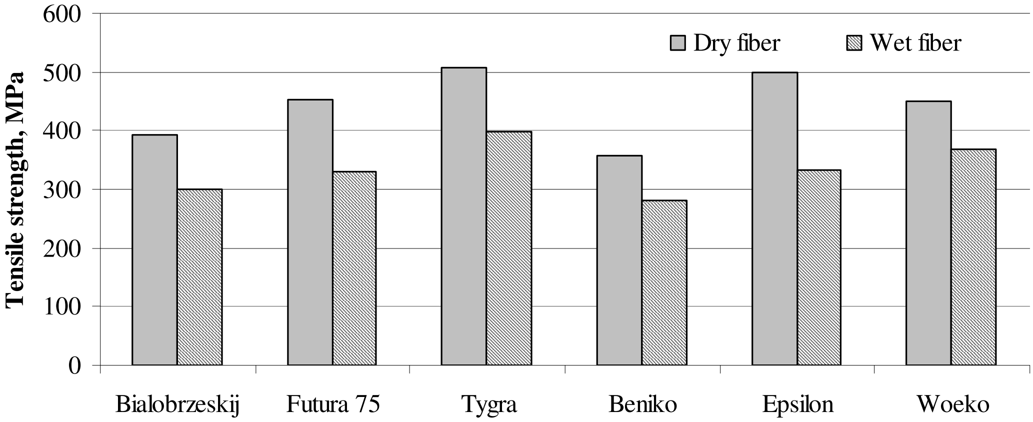

Fig. 4. **Tensile strength of hemp fibre depending on hemp varieties for dry and wet fibre**

After the experiment data processing, the average tensile strength of the two-year yield of six varieties of hemp was established. The 2011 crop variety 'Tygra' showed the highest average tensile strength. Its average tensile strength amounted to 558 MPa, which is equivalent to the tensile strength of high quality steel. The tensile strength of this variety in 2012th was 454 MPa, which is approximately equal to the variety 'Futura' tensile strength. Fibre tensile strength of the hemp variety 'Bialobrzeskie' was 361 MPa (harvest 2011) and 421 MPa (harvest 2012). The 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'. Strength differences in 2011 and 2012 for the other varieties were similar. The average of all varieties of tensile strength values are given in the Fig. 4. The biggest strength of dry fibres was found for the varieties ‘Tygra’ (506 MPa), ‘Futura 75’ (453 MPa) and ‘Epsilon’ (498 MPa). Large data dispersion during the experiments was determined for all hemp fibre samples. In the tensile strength determination experiments it reached ±150 MPa.

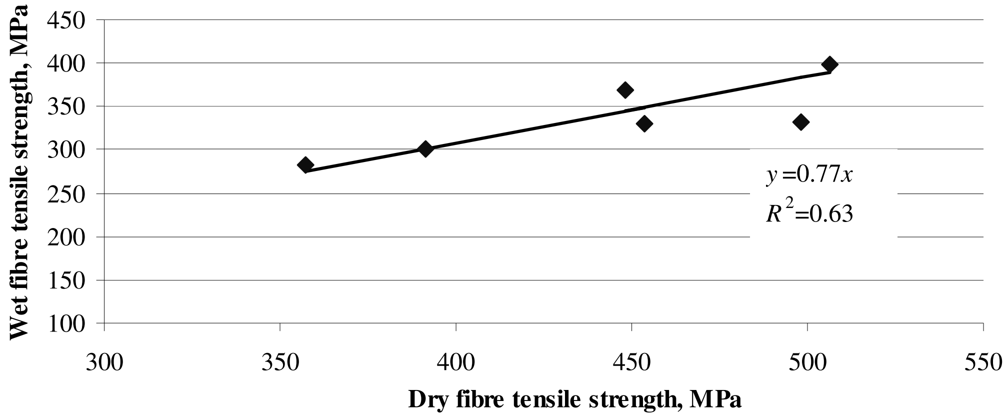

Fig. 5. **Wet fibre tensile strength depending on dry fibre tensile strength**

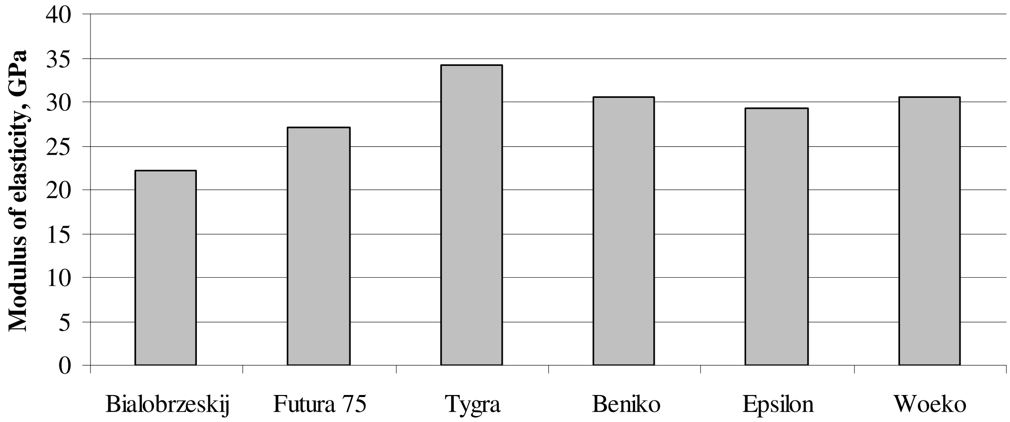

Fig. 6. **Modulus of elasticity for different varieties of hemp**

In order to assess the significance of differences in the tensile strength between the varieties of hemp statistical processing of data using t-test was carried out. Comparing the tensile strength of the variety ‘Tygra’ with the others, significantly lower tensile strength was found of the varieties ‘Beniko’ and ‘Bialobrzeskie’, $t_{stat} = 4.256$ ($p < 0.05$), critical $t = 2.57$.

Wet fibres showed a significant decrease in the tensile strength (Fig. 4.). The tensile strength for wet fibres decreases approximately in the same range for all varieties of hemp (Fig. 5). It is approximately 1.3 times less than the tensile strength of dry hemp fibres. Statistically evaluating the data obtained a significant difference between dry and wet hemp fiber was found, $t_{stat} = 6.65$ ($p < 0.05$), critical $t = 2.77$.

The modulus of elasticity was determined for all fibre samples (Fig. 6.). The greatest modulus of elasticity E = 37.9 GPa was stated for the variety ‘Tygra’ (harvest 2012), smallest E = 18.6 GPa for the variety ‘Bialobrzeskie’, harvested in 2012. Large data dispersion during the experiments was determined for hemp fibre samples. Modulus of elasticity of the hemp variety ‘Tygra’ lies between 31 and 44 GPa. The largest modulus of elasticity was found for the variety ‘Tygra’, but the lowest for the variety ‘Bialobrzeskie’ (Fig. 6).

Longitudinal and lateral compressive strength of hemp stems is important for determining hemp stems or shives as a reinforcement of foam gypsum panels. Seven varieties of hemp were tested to find the longitudinal and lateral compressive strength (Fig. 7-8).

Most longitudinal compressive strength was found for the variety ‘Santhica 27’ (26.4 MPa). The same variety gives the biggest lateral compressive strength (Fig. 8.). The varieties ‘Bialobrezskie’, ‘Futura 75’ and ‘Santhica 27’ can be recommended for foam gypsum reinforcement because of the largest compressive strength.

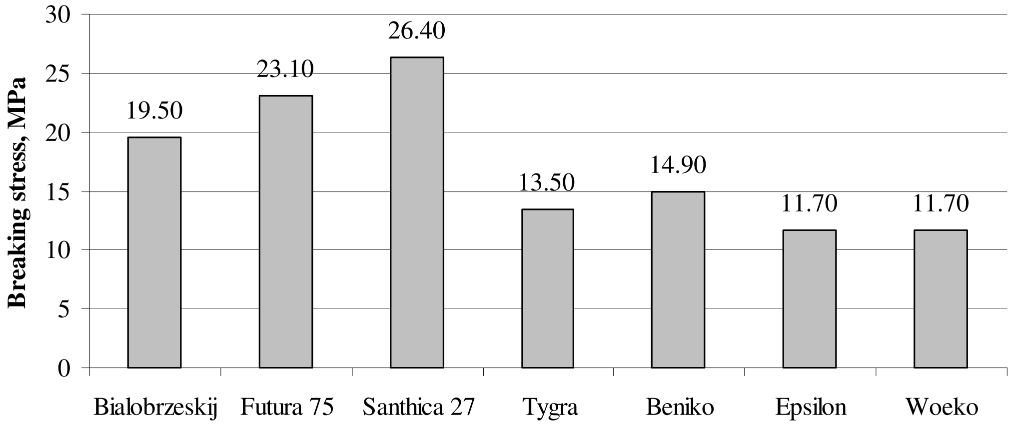

Fig. 7. **Longitudinal compressive strength of hemp stems depending on hemp varieties**

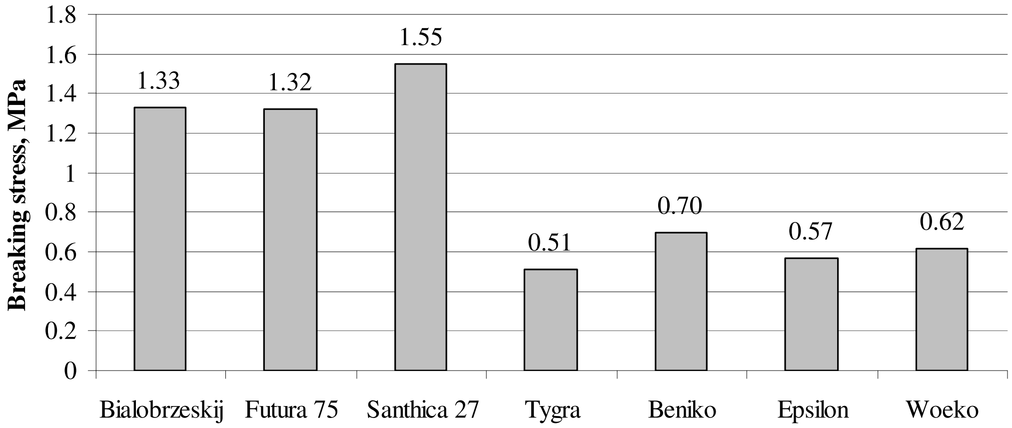

Fig. 8. **Lateral compressive strength of hemp stems depending on hemp varieties**

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

Conclusions

1. The greatest tensile strength 558 MPa was stated for the variety 'Tygra' (2011), but the hemp harvested in 2012 gave the tensile strength 454 MPa similar to the variety 'Futura'.
2. The biggest average tensile strength of dry fibres was found for the varieties 'Tygra' (506 MPa), 'Futura 75' (453 MPa) and 'Epsilon' (498 MPa).
3. The tensile strength of wet fibres compared with dry fibers decreases by 1.3 times on average for all hemp varieties.
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. The largest compressive strength was obtained of the hemp varieties 'Bialobrezskie', 'Futura 75' and 'Santhica 27'. These varieties are recommended for reinforcement of foam gypsum.
6. The tensile strength of all tested fibre samples is similar to the tensile strength of steel and is recommended for foam gypsum reinforcement.

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