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VERIFICATION OF MATERIAL CHARACTERISTIC OF NATURAL FIBERS FOR CONCRETE REINFORCEMENT

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Abstract. The topic of the article is the verification of the tensile mechanical characteristics of selected natural fibres commonly available on the Czech market. Due to their high tensile strengths, some natural materials have a certain potential for use in specific engineering applications such as concrete reinforcement. Additionally, natural fibres are renewable materials, making them an environmentally friendly material. Potentially, its use as a reinforcement in the form of technical textiles for textile-reinforced concrete could help create more sustainable reinforced concrete elements. This article deals with tensile tests of chosen available natural fibre materials, such as flax, hemp, jute, and sisal, both pure and impregnated (homogenised) using epoxy resin. In this article, the results and comparisons of tensile strengths and Young's modulus are presented.

Keywords: Natural materials, natural fibres, alternative reinforcement, tensile test, tensile strength.

1. Introduction

In recent years, there is great interest and pressure to reduce the environmental impact of structures due to the climatic crisis. Natural materials, which are renewable, are of great interest in many scientific fields. Due to the low price [1] and the relatively good characteristic of the material, natural materials have a great potential in the engineering industry. Today, there are already many applications for use in polymer composites for e.g., the automobile or aviation industry [2]. From the point of view of life-cycle assessment (LCA) [2], natural materials have a low environmental impact, because they are, for instance, renewable and composable [3].

Generally, textile-reinforced concrete (TRC) is reinforced by technical textiles from inorganic materials such as carbon, AR-glass, or basalt in a form of orientated rovings. The rovings are used as either pure or homogenised polymer matrix. The use of natural rovings or textiles in concrete could partially substitute the technical textiles, and technically this replacement is simply feasible. There is an option that both types of textiles might be used as hybrid reinforcement [4]. An important parameter for concrete reinforcement is the Young's modulus. In general, reinforcement should have a higher modulus of elasticity than the concrete matrix (around 20 GPa), because it needs to interact with the concrete matrix and must catch the crack development. Also, the amount of reinforcement in the cross-sectional area of the element should be less than the amount of concrete. Another basic parameter is the tensile strength, which is usually sufficient and thus the principle of composite behaviour of reinforced concrete is fulfilled. According to previous research, as seen in the presented Table 1 below, and according to the availability of the Czech market, four natural materials with the highest potentially mechanical performance were chosen for the basic testing of tensile mechanical parameters – flax, hemp, jute, and sisal. For reference, commonly used technical textiles were also experimentally verified – carbon, AR-glass and basalt rovings were used for testing and comparison.

2. Preparation of samples

From the Czech company "AGRITEC, výzkum, šlechtění a služby, s.r.o.", two types of natural fibres were received: flax and hemp. These specimens had to be woven manually by hand, as seen in the left picture of Figure 1. On the other hand, the Czech company "JUTA a.s." provided finished natural roving bulks of flax, hemp, jute, and sisal, so the work was easier as the rovings just needed to be cut into the required lengths.

Specimens were prepared for the tensile test. For the attachment of the sample to the claws of the hydraulic press, epoxy resin sleeves were required at the ends of the rovings. A silicone mould was created for the preparation of sleeves. There was an approximately 30 cm gap between the sleeves, as seen in the right image of Figure 1. Dimensions and test setup were prepared according to previous experience [6].

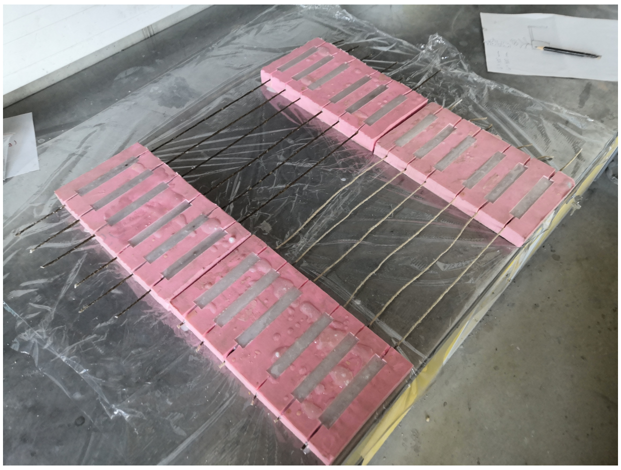
All samples were prepared in groups of 6 samples and in two variants – pure rovings without any treatment and homogenised rovings by epoxy resin. Homogenised filaments of roving interact between themselves which leads to better stress distribution throughout the cross-section, and therefore the sample withstands higher loads. The impregnation was done on a prepared frame to ensure that the rovings will be properly stretched.

The linear density of the rovings was around 1 600–2 500 tex depending on the bought available material.

Fibre type	Annual production [dry metric tons]	Density [$g\,cm^{-3}$]	Tensile strength [MPa]	Elastic modulus [GPa]	Elongation at break [%]
Softwood	1 750 000 000	1.4	100–170	10–50	8.0–14.0
Hardwood		1.4	90–180	10–70	11.0–13.0
Softwood kraft pulp	26 000 000	1.5	1 000	40	4.4
Jute	2 300 000	1.3–1.5	200–770	20–55	2.0–3.0
Sisal	378 000	1.5	100–800	9–22	3.0–7.0
Kenaf	970 000	1.4–1.5	930	53	1.6
Coir	100 000	1.2	180	4–6	30.0
Flax	830 000	1.5	350–1 040	28–70	2.0–4.0
Hemp	214 000	1.5	690	30–70	1.5–4.0
Bamboo	30 000 000	0.6–1.1	140–230	11–17	4.0–7.0
Wheat	720 000 000	0.6–0.8	10–200	1–12	2.7
Rice husk	120 000 000	0.7–1.0	55	22	2.0–5.0

Table 1. Overview of properties of selected natural materials [5].

(a).



(b).

Figure 1. Hemp and flax fibres arranged in single rovings (A) and poured sleeves with epoxy resin (B).

A full overview of the materials used and their characteristic is presented in the Table 2. The results were logically calculated in stress so that they can be compared.

	T [tex]	ρ_r [$g\,cm^{-3}$]	A_r [mm^3]
Flax	1 680	1.5	1.12
Flax handmade	1 850	1.5	1.23
Hemp	3 720	1.4	2.66
Hemp handmade	1 800	1.4	1.29
Jute	1 500	1.4	1.07
Sisal	2 000	1.5	1.33
Carbon	1 600	1.8	0.89
AR-glass	2 400	2.7	0.90
Basalt	2 520	2.7	0.94

Table 2. Material characteristic of measured rovings and yarns.

3. Experiment and results

The experiment was carried out on a GALDABINI Quasar 100 hydraulic press. The specimens were tested in tension with a constant load speed of $1\,mm\,min^{-1}$. The force and displacement of the upper jaw was recorded.

Young's modulus was measured by DIC (Digital Image Correlation). A large number of photos are taken during the experiment, and afterwards they are analysed in the software Istra4D. Identified unique areas of pixels are tracked, and deformations are counted. The samples were provided with small spackle pattern targets for a good measurement of the deformations, as seen in Figure 2 and Figure 3. The photos for the DIC analysis were taken in an interval of 0.5 seconds.

The impregnated samples were also measured with an extensometer (Figure 3) for validation of the data from DIC. Samples without impregnation could not be measured with the extensometer, because the jaws

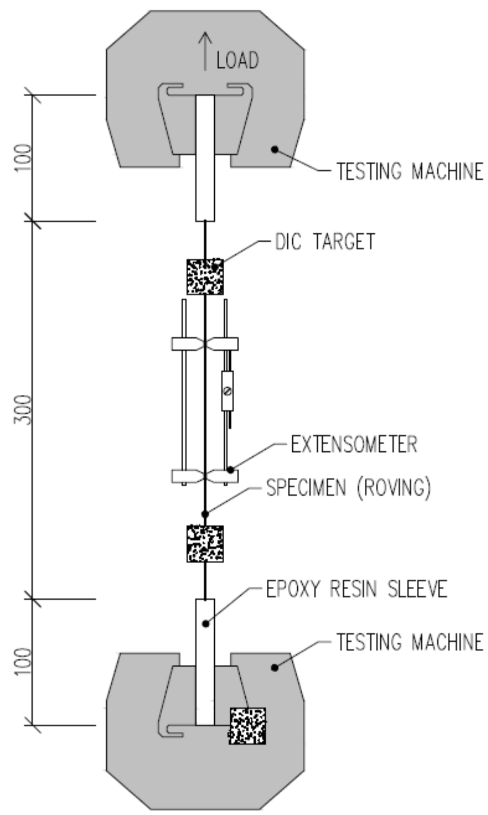
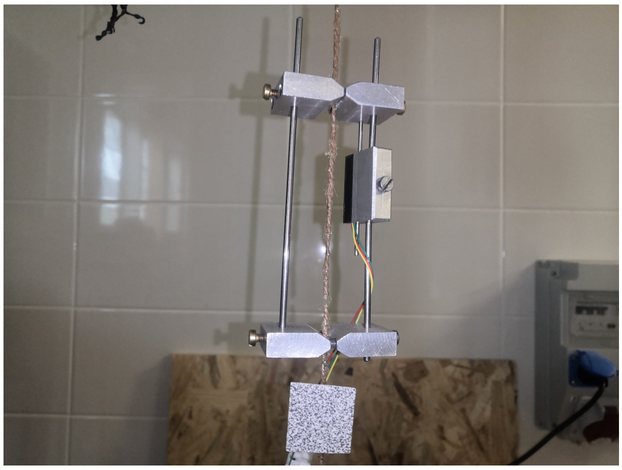


FIGURE 2. Scheme of the tensile test setup.

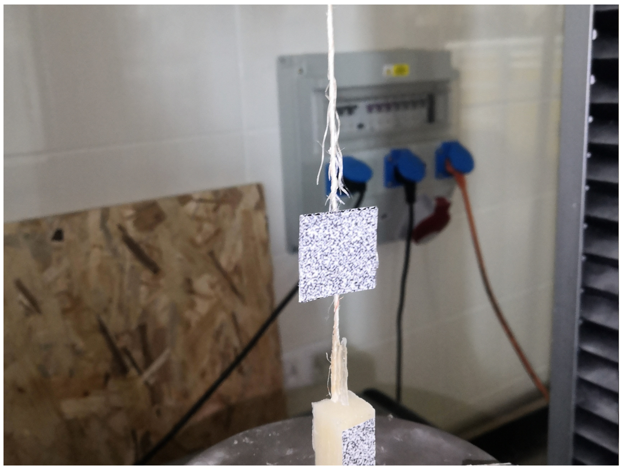
of the extensometer would damage the pure roving. The handling of the extensometer is also very time consuming. The pure rovings were twisted 5 times every time before the specimen was placed into the press jaws. By this the filaments were prestressed a little so that the distribution of force was better throughout the cross-section of the roving due to the mechanical interaction of single fibrils. Then the filaments did not break too much one by one, and some data could be measured. [7]

In the Table 3, there are presented the results of measurements. There is a comparison of the Young's modulus measured by DIC and extensometer on impregnated flax specimens. The values of both methods are very similar. The data measured with the extensometer have slightly lower deformations and therefore higher Young's modulus.

But as seen in Figure 4, some data, such as flax, have bigger differences. This inaccuracy might be caused by the experiment setup. Around loading force of 250 N there was a jump in the data measured by DIC. It was caused by the lower jaws of the press, which were slightly raised. The force of 250 N approximately corresponds to the weight of the steel part (15.6 kg) and friction in placement. Therefore, the data measured with the extensometer are more precise and reliable. On the other hand, if the setup of the experiment is prepared thoroughly, then the DIC method is much easier and faster to handle.



(A).



(B).

FIGURE 3. Impregnated jute yarn with extensometer and DIC target (left). Pure sisal yarn with DIC target after failure (right).

	σ_{max} [MPa]	E_{DIC} [MPa]	E_{EXT} [MPa]
Flax epox	522	25 933	28 078
Flax pure	126	8 104	
Flax epox handmade	370	40 201	43 418
Flax pure handmade	107	11 706	
Hemp epox	315	18 702	20 849
Hemp pure	150	5 390	
Hemp epox handmade	275	20 042	21 647
Hemp pure handmade	115	5 913	
Jute epox	311	24 794	28 029
Jute pure	161	7 188	
Sisal epox	349	21 188	22 905
Sisal pure	231	8 135	

TABLE 3. Measured data of stress and Young's modulus on natural yarns and technical rovings.

The results in the Table 3 and Figure 5 clearly state that the impregnated rovings have higher strength and stiffness than the pure ones, because the impregnation allows to transfer the stress effectively through

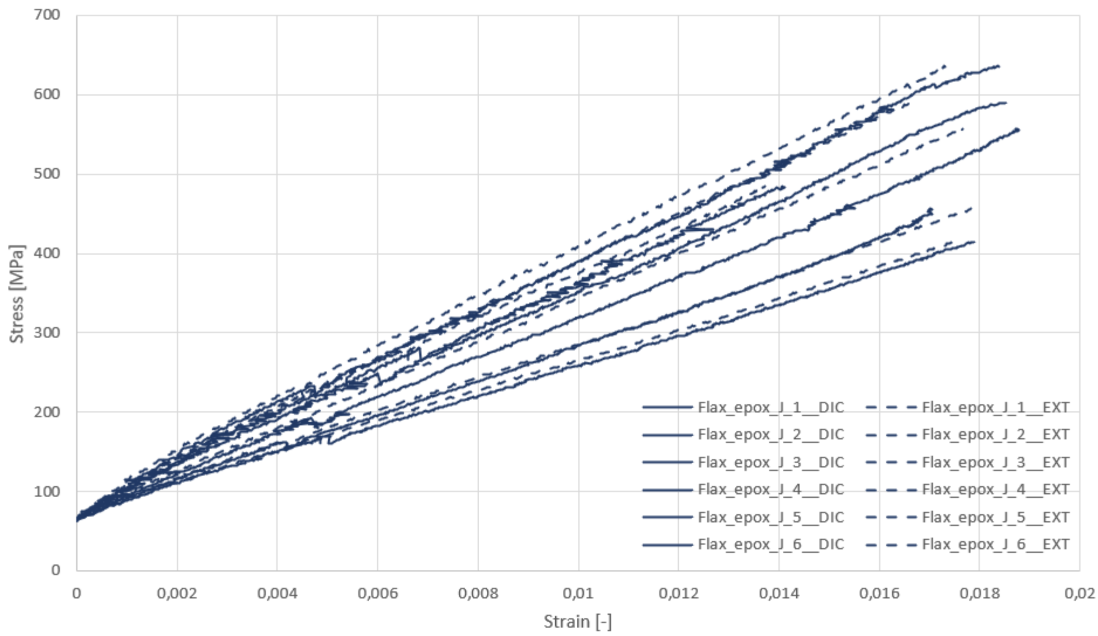


Figure 4. Comparison of the flax data measured by DIC and extensometer.

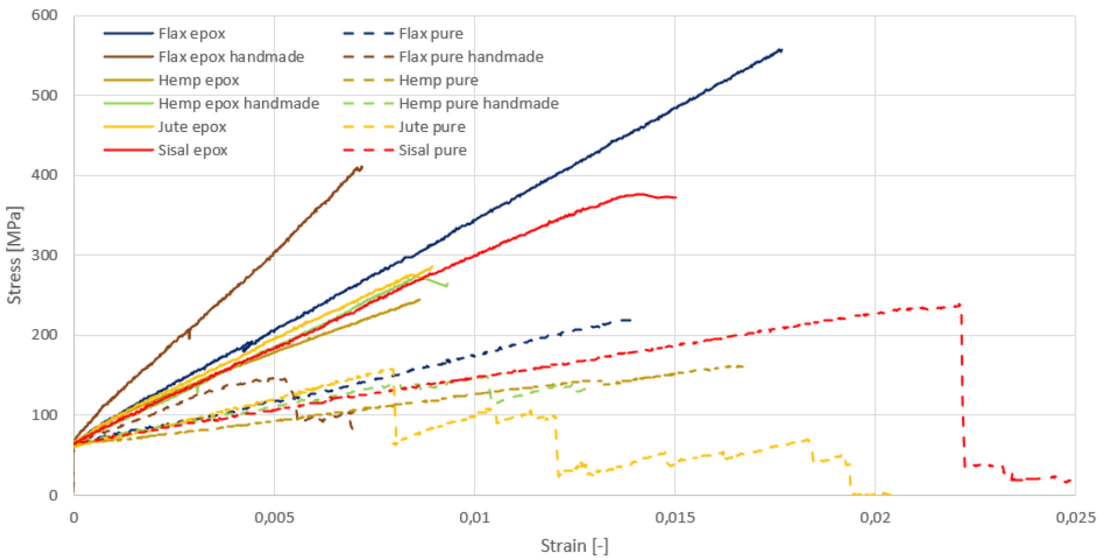


Figure 5. Stress-strain chart of representative samples of pure and impregnated samples.

the whole cross-section. The filaments of pure rovings break one by one, which makes it very difficult to measure any relevant characteristic data of the material. On the other hand, it shows ductility, which might be potentially useful in the reinforcement of concrete. In addition, only impregnated rovings are evaluated as their values are more relevant to the theme of this paper.

In terms of modulus of elasticity, the results are quite similar except for flax. Handmade prepared flax roving shows the best average Young's modulus with the value of 43.4 GPa. Generally, flax and hemp plants have a better structure of plant cells – microfibrils have a low angle deviation from the direction of growth, which is a good prerequisite for tensile strength and stiffness [8]. The reason behind the large deviation of handmade flax might be a different type of flax plant or also the process of specimen preparation. The filaments of handmade prepared roving were placed parallel one to each other, as seen in Figure 1, but the commercially woven yarn is twisted, and the material might be more damaged by the process of making.

4. Conclusion

Generally, it can be said that the theoretical assumptions were correct. Flax seems to be the right material to continue the research of concrete reinforcement in the form of a technical textile. The best was hand-made flax with an average Young's modulus of 43.4 GPa. The best average tension strength had commercially bought flax with a value of 522 MPa. The differences between the rest of the natural materials were small, and it probably largely depends on the origin of the material.

Two methods of measuring the modulus of elasticity were tested – with DIC and with an extensometer. Both methods showed similar and solid results. The DIC method is faster and easier to deal with, but the setup of the experiment must be well prepared. The extensometer method is more reliable but more demanding.

The material characteristics of the chosen natural materials were described in this article. It can be said that measured flax data show good potential as a concrete reinforcement for specific applications, as the Young's modulus of concrete is around 20–40 GPa.

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