Acta Polytechnica CTU Proceedings **49**:36–40, 2024
https://doi.org/10.14311/APP.2024.49.0036

MEASUREMENT OF TENSILE PROPERTIES OF SELECTED ROVINGS

Věra Kabíčková[a, b, *], Jakub Hájek[a, b], Jan Macháček[a, b], Eliška Kafková[a], Tomáš Vlach[a, b]

[a] *Czech Technical University in Prague, Faculty of Civil Engineering, Department of Architectural Engineering, Thákurova 7, 166 29 Prague, Czech Republic*

[b] *Czech Technical University in Prague, University Centre for Energy Efficient Buildings, Třinecká 1024, 273 43 Buštěhrad, Czech Republic*

[*] corresponding author: vera.kabickova@fsv.cvut.cz

Abstract. This article is focused on measuring the tensile properties of chosen fibre materials, such as flax, alkali resistant glass or viscose. All selected materials were tested both pure and impregnated using epoxy resin. In this article, the tensile strength and the Young's modulus were observed. Young's modulus was measured using Digital Image Correlation. The suitability of the location of small speckle pattern targets, which are used for measurements of deformations, was first verified on the viscose fiber samples. Targets were applied directly to the roving and further to the sleeves made of epoxy resin used to fix samples in the test equipment. After the evaluation, the selected location was then applied to the selected types of rovings. Finally, the measured results were compared.

Keywords: Roving, tensile strength, modulus of elasticity, digital image correlation.

1. Introduction

Civil engineering in general and especially cement production remains as one of the highest CO_2 emitters in the industrial sector. Significant efforts need to be made on promoting material efficiency and innovation in order to limit its negative impact on the environment [1]. This goes hand in hand with the development of alternative reinforcements in the form of composite and various fibers. Fiber-reinforced polymer (FRP) rebars as an alternative composite reinforcement have been considered as a non-corrosive alternative, but they are also associated with specific disadvantages [2]. Synthetic fibers such as carbon, basalt or alkali-resistant glass reach high mechanical properties, FRP rebars as a combination of epoxy resin with these fibers are logically less stiff and significantly less ductile when compared to steel rebars [3]. For the FRP reinforcements, there are several rovings (yarn) together in one rebar. Finer reinforcement from individual roving woven into technical textiles is also used as an alternative reinforcement for subtle concrete elements or in combination with traditional steel reinforcement for constructions. This type of reinforced concrete is called textile reinforced concrete (TRC). Technical textiles are usually applied without any impregnation, only with surface alkali-resistant coating, or impregnated using epoxy or polyester resin. The basic material parameter of this reinforcement in addition to the linear density of the yarn, interaction conditions and other basic information is the tensile strength of the reinforcement (single roving) and a Young's modulus of elasticity in tension. This article deals with these two basic material parameters.

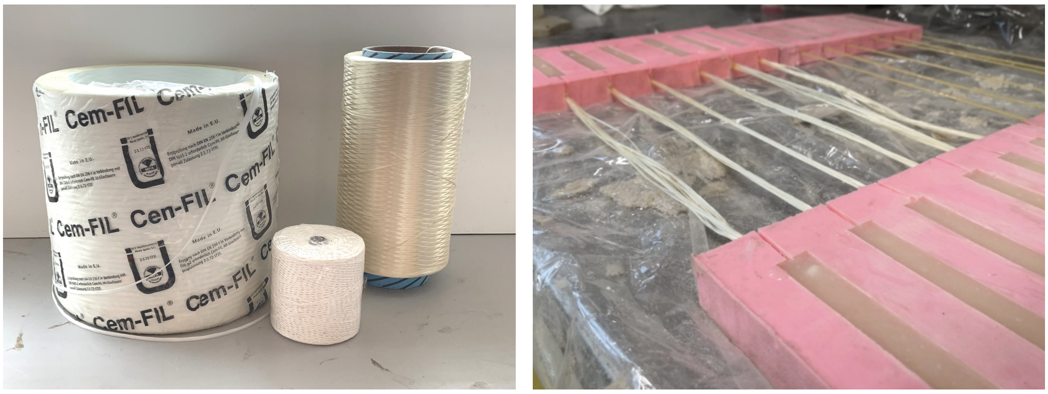
For this article, which is focused on the basic tensile parameters, the procedure according to ACI 440.3R-04 about the test methods for fibre-reinforced polymers (FRP) for reinforcing or strengthening concrete structures was chosen and adapted, but due to the smaller cross-sectional area, it was more inspired by [4]. This method was developed for multi-filament yarns without any impregnation, but the same testing procedure was applied to the tensile testing of single roving with epoxy polymer matrix. To secure the samples to the testing machine epoxy sleeves on both sides of roving were used. Comparison of different methods for the determination of the modulus of elasticity of composite reinforcement produced from roving was also described in [5], the tensile strength and static modulus of elasticity were measured and calculated in [6].

2. Materials and methods

2.1. Materials and samples

For the experiment, three different fiber materials were chosen – alkali resistant glass, flax and viscose (Figure 1). Alkali resistant glass is already commonly used as a reinforcement in concrete structures, but research shows that natural fibers can also be considered as an alternative concrete reinforcement [7]. Flax has the best mechanical parameters of natural fibers. On the other hand, viscose, which is produced from natural material and is industrially compostable, has a great ductility. These materials were mutually compared.

The alkali resistant glass fibres roving Cem-FIL® 5325 had the length weight of 2 400 tex



(a). Alkali resistant glass, flax and viscose fibers. (b). Preparation of samples.

Figure 1. Rovings used.

Fiber type	Specific gravity [g/cm^3]	T [tex]	Tensile strength [MPa]	Elastic modulus [GPa]
AR glass (Cem-FIL® 5325)	2.68	2 400	>1 000	72.0
Flax	1.40–1.50	1 680	343–2 000	27.6–103.0
Viscose	1.51	1 840	210–530	3.0–4.5

Table 1. Material characteristics of used roving [8–13].

(=2 400 g km^{-1}), the specific gravity of 2.68 g cm^{-3}, the tensile strength of more than 1 000 Mpa and the modulus of elasticity of 72 GPa. The theoretical maximum tensile force before breaking of all fibers at one time calculated from the technical data sheet is more than 896 N [8].

Another material used is flax. The chosen roving had the length weight of 840 tex, so two rovings were laid next to each other to reach a value of approximately 1 600 tex for better comparison [9] The primary use of natural flax roving is in the food industry, which means that there are not many mechanical properties available. In addition, its mechanical properties vary depending on many conditions, such as the production process (growth conditions, harvesting, etc.) or relative humidity. In literature, it can be found that the specific gravity is around 1.5 g cm^{-3}, the tensile strength is between 343–2 000 Mpa and the modulus of elasticity varies between 27.6–103 GPa [10, 11].

The last selected material was viscose. The viscose fibres roving Viscord® had the length weight of 1 840 tex. Viscose fibers have the specific gravity of 1.51 g cm^{-3} and usually reach the modulus of elasticity of 34 Mpa. There is a certain scatter of tensile strength, which varies between 210–530 Mpa [12, 13]. The characteristics of the materials can also be seen in Table 1.

Some rovings were impregnated with 2-part epoxy resin Sikafloor 150. The mixing ratio of Part A and Part B was 74:26 by weight [14].

To ensure fixation of the samples to the testing machine, both ends were fitted with the epoxy prisms 15 × 15 × 100 mm, as seen in Figure 1. The distance between these prisms was 300 mm. This method of preparation followed A novel tensile test device for effective testing of high-modulus multi-filament yarns by R. Rypl et al. [4].

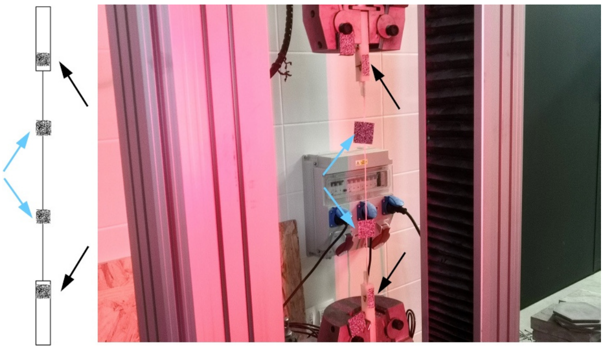


Figure 2. The location of the small speckle pattern targets.

2.2. Experiment

For the experiment, GALDABINI Quasar 100 hydraulic testing machine was used. The samples are fitted with small speckle pattern targets, which allows the area to be tracked, and the deformations are then calculated. For this experiment, two locations of the targets were chosen – directly to the roving (Figure 2, blue arrows) and further to the epoxy prisms (Figure 2, black arrows). The suitability of the location of these targets was first verified on the viscose fiber samples and the selected location was then applied to the other types of rovings. Especially in the case of samples without epoxy resin (pure roving), the small speckle pattern targets may rotate during the experi-

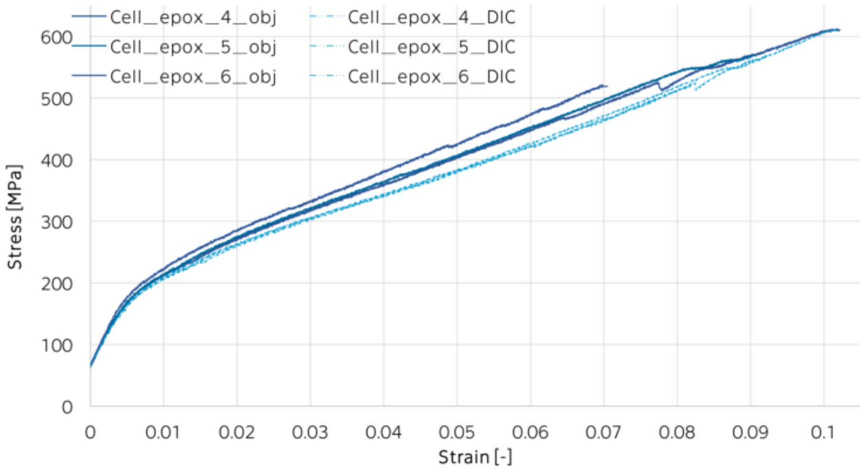


FIGURE 3. Comparison of chosen viscose data (DIC_obj – the targets on the prisms, DIC – the targets on the roving).

Fiber type	σ_{max} [MPa]	E_{DIC_roving} [GPa]	E_{DIC_prisms} [GPa]	Deviation [%]
Cell epox_2	610	6.93	7.67	10.8
Cell epox_3	621	7.50	8.68	15.7
Cell epox_4	612	7.21	8.18	13.4
Cell epox_5	569	6.38	7.28	14.1
Cell epox_6	521	5.42	6.80	25.3
Average	587	6.69	7.72	15.5

TABLE 2. Data of Tensile strength and Young's modulus of elasticity measured on the viscose samples using DIC.

ment. This may cause deviations in results, or even interruption of measurement. Speckle pattern targets on the edge of epoxy prisms do not rotate and are easily applied, but apparently will be influenced by a change of the stiffness.

The samples were tested in tension with a constant loading speed of 1 mm min^{-1} and the force and displacement were recorded. Another observed value was the Young's modulus. For the measurement of this value, DIC (Digital Image Correlation) was used. Photos taken during the experiment are then evaluated by the Istra4D software. The photos for the DIC analysis were taken in an interval of 0.5 seconds. As mentioned in the introduction, the test method was inspired by standard of American Concrete Institute ACI 440.3R-04 and adapted due to the smaller cross-sectional area. This adjustment was mostly inspired by [4] for multi-filament yarns without any impregnation and used also for the homogenized ones.

3. Results and discussion

First, the effect of the location of small speckle pattern targets was measured. In previous measurements an extensometer was used for the alkali resistant glass roving and results were similar [15]. Using extensometer is more reliable, because it does not matter whether the roving rotates during the loading process. But also it is more demanding and can't be used at pure rovings because of the damage of fibers during the installation. In contrast with extensometer, using DIC is easier, but the setup of the experiment must be more thorough. One the other hand, it is possible to measure a larger number of samples in a short time. But there is another problem associated with DIC and that is the location of the targets – when the targets are on the roving, as previously mentioned, they tend to rotate during the experiment (as seen in Figure 2 on the upper target) and there is a risk that the DIC camera would stop measuring due to the loss of the targets. Placing the targets on the epoxy prisms would solve this problem ever since it cannot rotate, on the other hand final results can be affected by many other influences (such as the effect of the supports). In this part of the article, the impact of targets' location was first verified on the viscose fibers rovings. According to the technical data sheet, the viscose has the highest elongation and seems to be the best for this verification.

Figure 3 shows that the courses of the curves are similar, but the slopes of the curves measured from prisms are steeper. In Table 2, the results of measurements are presented. We can see a comparison of the Young's modulus and the deviation from the values measured from rovings despite the fact that the targets were placed on the edge of the epoxy prism. The values measured from prisms are higher than from roving and the average deviation is 15.5 %. This deviation is caused by higher stiffness of the prisms. It can also be seen Table 2 that the deviation fluctuates

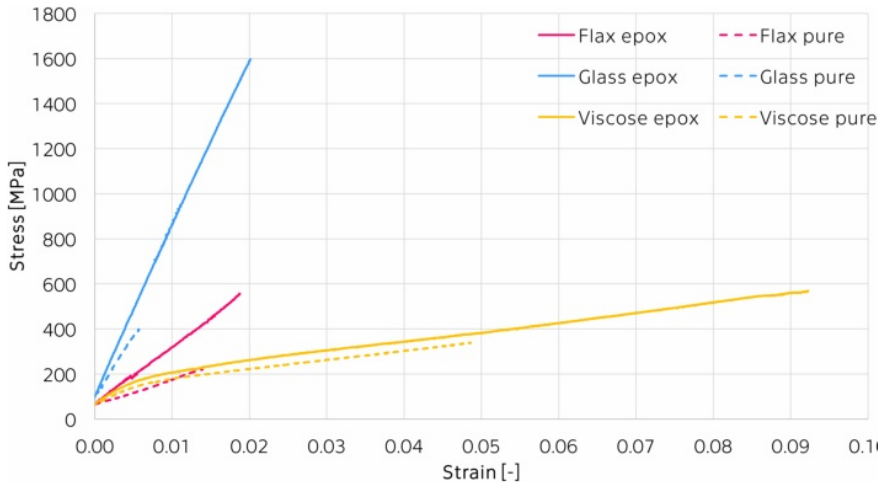


FIGURE 4. Stress-strain chart of chosen samples of pure and impregnated rovings.

Fiber type	σ_{max} [MPa]	E [GPa]
Flax epox	522	25.93
Flax pure	126	8.10
Glass epox	1 534	75.03
Glass pure	390	52.05
Viscose epox	587	6.69
Viscose pure	389	5.86

TABLE 3. Average data of Tensile strength and Young's modulus of elasticity.

significantly. Placing the targets on the epoxy prisms is therefore not very reliable.

Afterwards, all types of rovings, both pure and impregnated, were measured using DIC and, according to the results above, the targets were placed directly to the rovings. The results in the Figure 4 and Table 3 shows that the pure rovings reach lower strength and stiffness than the impregnated rovings. It is caused by the fact, that the stress cannot be transmitted through the whole cross-section of roving as in the case of the impregnated roving. All fibrils, thanks to the epoxy resin homogenization, then collapse at once.

It was also found that values of impregnated alkali resistant glass rovings are closer to those in the literature compared to the pure ones (measured Young's modulus of pure glass roving is 52 GPa, measured Young's modulus of impregnated glass roving is 75 GPa and the value of the Young's modulus in the literature is 72 GPa). However, this conclusion cannot be applied to all types of fibers. Since mechanical properties of natural fibers depend on many conditions (in addition, in the case of viscose fibers, many mechanical properties are not available), most of the measured values fit within the range of values in the literature.

The highest Young's modulus reach glass fibers with the value of 75 GPa, the lowest reach viscose fibers with the value of 6.7 GPa. This seems to be significantly lower, on the other hand, viscose fibers show by far the highest ductility, which may be useful in terms of reinforced concrete.

4. Conclusion

As expected, pure rovings without epoxy resin have significantly worse results, because there are gradual violations of individual fibrils. Similar behavior like presented results happens inside of the concrete matrix with textile reinforcement produced from rovings. In the textile reinforcement without impregnation, there is no full saturation of roving by cementitious particles and the fibrils collapse gradually. This leads to a reduction in load-bearing capacity, but to an increase and better behavior in ductility. The suitability of the use of pure, partially, or fully homogenized roving is determined by the specific applications and requirements.

Presented comparison of the selected materials was also more or less expected. The best potential as a reinforcement of concrete has alkali resistant glass roving, which has a relatively high Young's modulus of elasticity and is able to capture a possible crack initiation in concrete quickly. Also, flax has an interesting value of the elastic modulus, which is approximately similar to the static modulus of traditional concrete. This means that a large amount of reinforcement would have to be in the cross-section of the bend stressed element to bridge the crack. Due to the very low modulus of elasticity, viscose has almost no potential as a reinforcement in concrete elements, although the value of tensile strength is satisfactory.

Acknowledgements

The work on this paper was supported by Czech Science Foundation Grant No. 22-14942K entitled "Possibilities of using natural fibers for the production of hybrid textile reinforcement in concrete". The authors would like to acknowledge all financial assistance provided to support this research.

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