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Characterization of hemp yarn with alkaline surface treatment for polymer matrix composite applications

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Abstract. Nowadays, composite materials are widely used in many applications ranging from aerospace to construction. In addition, natural yarns have become one of the emerging types of reinforcements used in composite materials as they are bio-degradable; hence, environmentally friendly. Therefore, this paper aims to study the effects of alkaline treatment on hemp yarns and characterization of treated hemp yarn reinforced composite. The hemp yarns are immersed in NaOH solution 5%wt/vol. at room temperature for 48 and 72 hours, respectively. The results show that the surface modification using alkaline treatment helps reduce lignin, wax and other contaminants, which potentially improves adhesive strength between the yarn and the polymer matrix of the composite. This is because the aforementioned level of concentration and immersed time of alkaline treatment helps roughen the yarn surface; hence, the adhesion between the yarn and the matrix is better.

1. Introduction

Recently, global warming is one of alarming environmental problems that is of interest by scientists and researchers around the world. Therefore, new raw materials, which are environmentally friendly are needed. Natural fibers are one of these materials and they are used to be the reinforcement for composite materials to replace the synthetic fibers, such as glass or carbon fibers. The plant fibers are the main type of natural fibers used for composite materials today as they are cheap, recyclable, easy to produce, has low density and low processing energy consumption.

Plant yarns consist of many relatively short fibers twisted at an angle with respect to yarn axis in order to provide axial strength to the yarn. The commercial plant yarn has various types, such as cotton, jute, flax and hemp. The cotton yarn is the most popular type in the world, therefore, this type is the most widely studied. However, hemp yarn is an emerging European industrial crop, which (European Industrial Hemp Association (EIHA) reported that hemp was cultivated on 10,000 to 15,000 ha in 2012 and approximately 14.4% was used for bio-composites applications, for example, automotive interior applications with a share of 96% of all bio-composites [1].

In Thailand, hemp yarns are illegal because hemp has similar effects as marijuana, that is one of the narcotic plants according to Thailand's law. Hence, the hemp yarn has been used to only produce textile fabrics. In the past, there have been many studies about characteristics of hemp yarn for textile applications, but this paper focuses on the characteristics of hemp yarns for composite materials potentially used for automotive applications. This paper aims to study hemp yarn in terms of yarn structure and mechanical properties. These characteristics can help determine Thailand's hemp yarn whether it is suitable to use for engineering applications.

2. Materials and methods

The Hemp yarns were separated from plain weave woven hemp fabric. The yarn has a nominal linear density of 132.77 tex (g/1000m) measured from the dry weight of 10 m fabric sample.

The Alkali-treated yarns were extracted from alkali-treated fabrics, which were immersed in 5% wt./vol. NaOH solution (pH = 14) for 48 and 72 hours, then washed with distilled water until the pH reached about 7, then the treated fabrics were dried at ambient temperature for 24 hours. Finally, these fabrics were dried in an oven (DHG-9053A) at 60 ^{o}C for 2 hours.

2.1. Cross-sectional area

The cross-sectional area's specimen was made of hemp yarns and polyester (Figure 1). Hemp yarns were laid in polyester, after polyester cured, then polished it by sandpaper until surface of specimen is clear. The cross-sectional area of hemp yarns was determined from the specimen with Olympus BX51M optical microscope image, then the Image J software was used, using binary and analyze particles function, to determine the cross-sectional area of the yarns.

Figure 1. Specimen for the cross-sectional area determination.

2.2. Mechanical properties

The mechanical properties were measured with a Mecmsin Multitest 2.5-i machine according to ASTM D2256 for single-strand hemp yarn specimens in straight configuration, with load cell setting of 100 N and cross-head speed of 5 mm/min. The gauge length was 250 mm and the temperature in the testing room was controlled at 20 ± 1^{o}C. The sample yarns were attached to the vertical center line of cardboard, in which the cardboard protects the hemp yarn from damage caused by the grip of the tensile testing machine, with clear adhesive tape as shown in Figure 2.

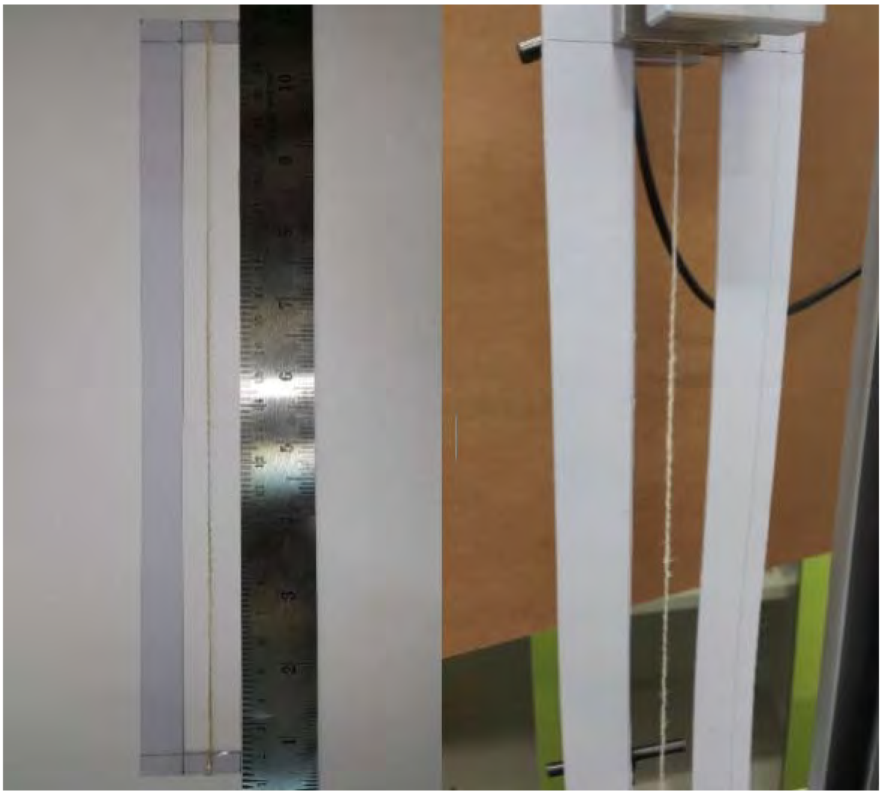


Figure 2. Sample yarns specimen for tensile test. Gauge length was 250 mm.

3. Results and discussion
3.1. Yarn structure
Figure 3 shows the yarn cross-sectional shape, which comprises of a group of single fiber of different sizes and gap between each fiber. Cross-sectional area of the yarn was determined from accumulation of cross-sectional areas of all fibers.

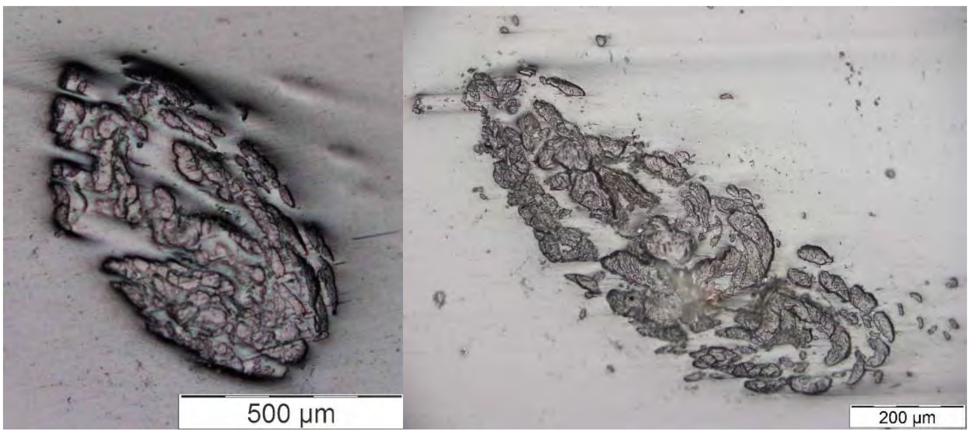
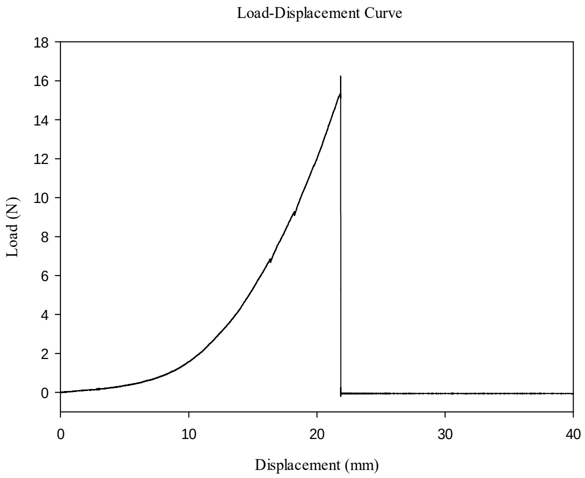
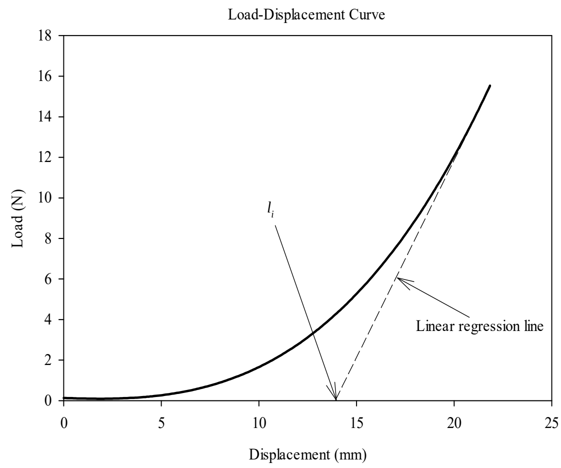


Figure 3. Cross-section of sample hemp yarns (10×, left, and 20×, right, magnification).

3.2. Mechanical properties



(a)



(b)

Figure 4. Example of a load-displacement curve for hemp yarn, (a) the complete curve and (b) a close-up of the initial non-linear part.

The tensile test of the hemp yarn shows that the initial part of the load-displacement curve is non-linear, but the curve slowly increases to linear (Figure 4 (b)). The length of the non-linear part is highly dispersed among otherwise identical yarn samples, and, as a result, this increases scatteredness of the stress-strain curves. The difference is set off by using linear regression to extend the linear part of the curves to the axis of displacement, and the point of intercept (l_i) was subsequently used in the calculation of strain (ε):

$$\varepsilon = \frac{\Delta l - l_i}{l_0}$$

where Δl is the displacement and l_0 is the gauge length [2].

The calculation of stress (σ):

$$\sigma = \frac{F}{A}$$

where F is tensile force and A is cross-section area of yarn. For each stress-strain curve, the apparent stiffness (the slope of the linear part; GPa), the ultimate stress (MPa), and the strain at ultimate stress were determined.

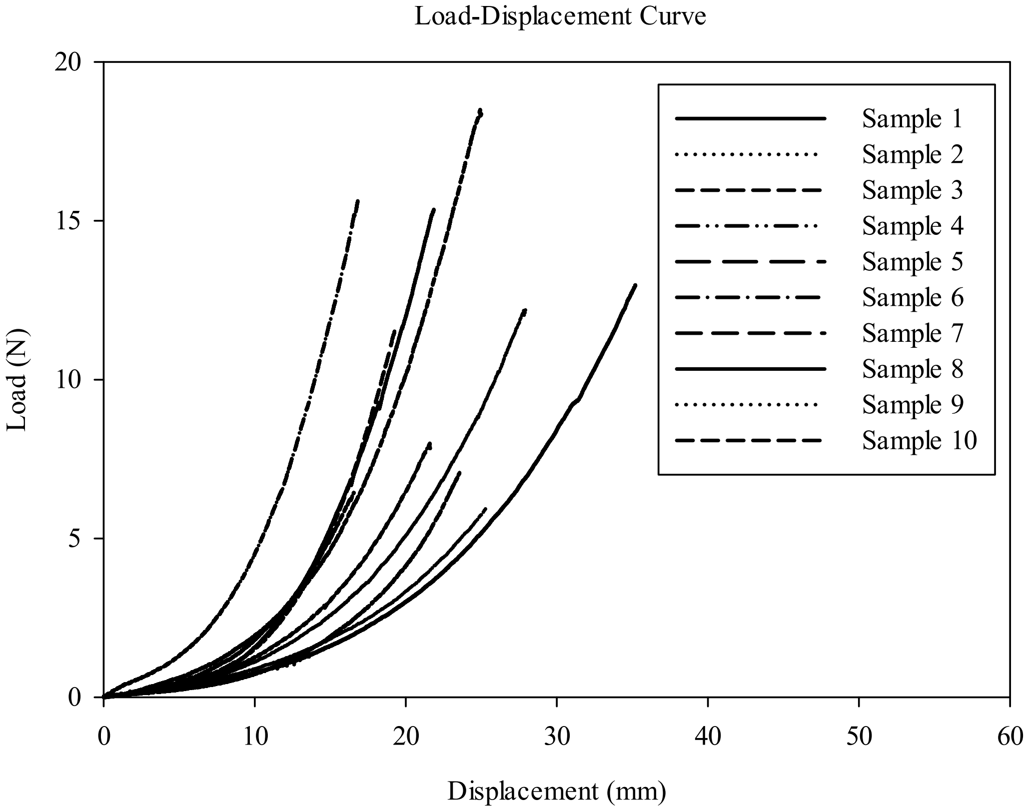


Figure 5. Load-displacement curve of sample hemp yarns.

Figure 5 shows load-displacement curve of sample hemp yarns. Sample 7 can resist the load more than sample 5 has. Interestingly, the sample 5 is the yarn that has the highest cross-sectional area of all samples but can resist the load less than the sample 7, which has cross-sectional area less than the sample 5. Because the sample 7 was compound with the big fibers more than the sample 5 (Figure 3 shows the two sample yarns were compound from different size of fibers). So, the yarn which has big fiber more than, it can resist the load more than another yarn.

Figure 6 shows the measured stress-strain curves of the untreated hemp yarns. The curves are cut off at the point of ultimate stress. The means ± stdvs. of extracted mechanical properties parameters (Table 1) show that untreated hemp yarns have apparent stiffness 3.594±2.406 GPa (sample 5 is the highest), ultimate stress 164.002±93.830 MPa (sample 8 is the highest), and strain at ultimate stress 0.036±0.009 (sample 1 is the highest).

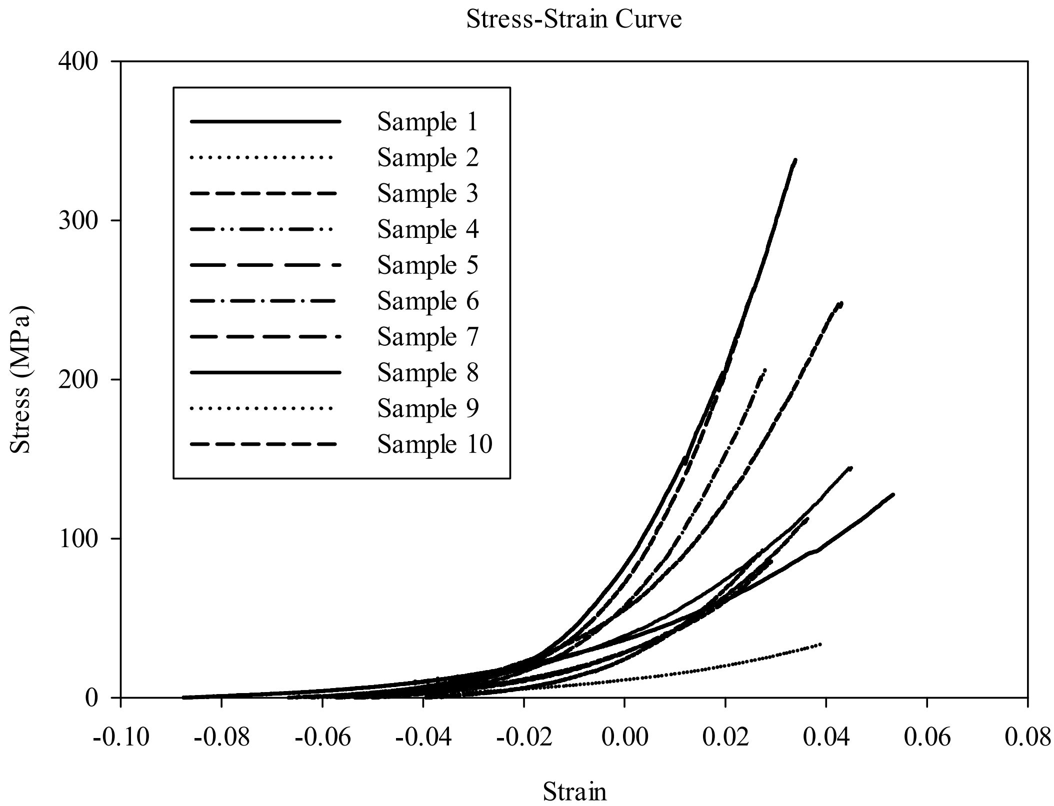


Figure 6. Stress-Strain curve of untreated hemp yarns

Table 1. Mechanical properties of the untreated hemp yarns.

Sample No.	Apparent Stiffness (GPa)	Ultimate stress (MPa)	Strain at ultimate stress
1	1.718	127.704	0.053
2	0.579	34.078	0.039
3	2.494	92.628	0.027
4	2.269	111.419	0.037
5	7.196	250.467	0.025
6	5.333	206.108	0.028
7	4.477	248.236	0.043
8	7.543	338.228	0.034
9	2.363	145.493	0.045
10	1.967	85.655	0.029
means ± stdvs.	3.594 ± 2.406	164.002 ± 93.830	0.036 ± 0.009

Figure 7 shows the measured stress-strain curves of 48 hr alkali-treated hemp yarns. The curves are cut off at the point of ultimate stress. The means ± stdvs. of extracted mechanical properties parameters (Table 2) show that untreated hemp yarns have apparent stiffness 3.249±1.151 GPa (sample 1 is the highest), ultimate stress 135.880±35.610 MPa (sample 1 is the highest), and strain at ultimate stress 0.031±0.003 (sample 5 is the highest).

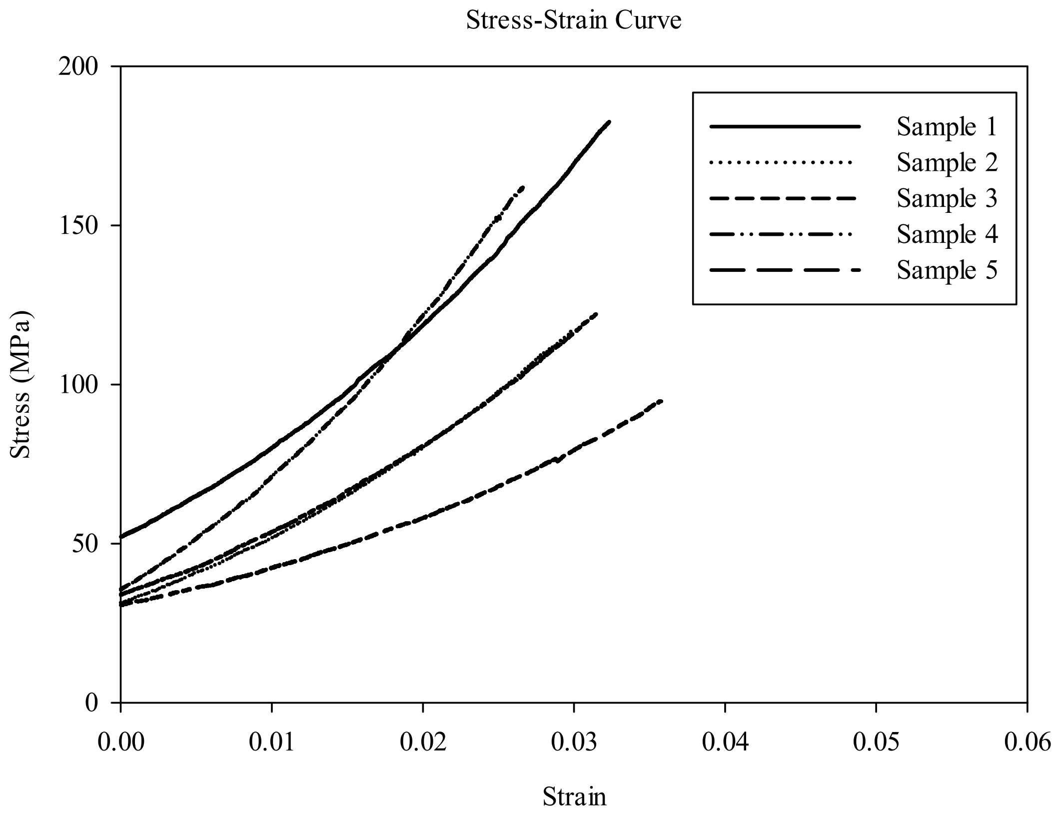


Figure 7. Stress-Strain curve of 48 h alkali-treated hemp yarns.

Table 2. Mechanical properties of the alkaline treatment hemp yarns.

Sample No.	Time of treatment (hours)	Apparent Stiffness (GPa)	Ultimate stress (MPa)	Strain at ultimate stress
1	48	4.034	182.650	0.032
2	48	2.870	117.401	0.030
3	48	2.812	122.640	0.032
4	48	4.738	161.932	0.027
5	48	1.790	94.778	0.036
means. ± stdvs.		3.249 ± 1.151	135.880 ± 35.610	0.031 ± 0.003

Figure 8 shows the measured stress-strain curves of 72 h alkali-treated hemp yarns. The curves are cut off at the point of ultimate stress. The means ± stdvs. of extracted mechanical properties parameters (Table 3) show that untreated hemp yarns have apparent stiffness 1.768±0.513 GPa (sample 4 is the highest), ultimate stress 76.166±25.291 MPa (sample 4 is the highest), and strain at ultimate stress 0.031±0.003 (sample 4 is the highest).

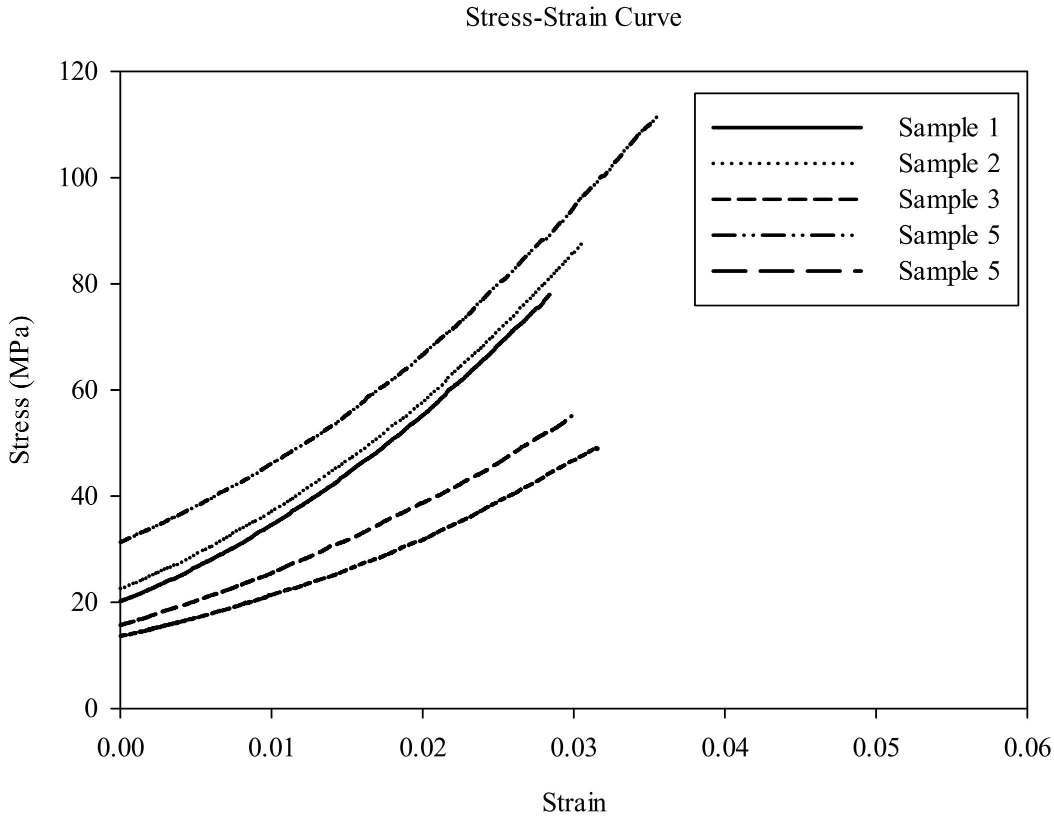


Figure 8. Stress-Strain curve of 72 h alkali-treated hemp yarns.

Table 3. Mechanical properties of the alkaline treatment hemp yarns.

Sample No.	Time of treatment (hours)	Apparent Stiffness (GPa)	Ultimate stress (MPa)	Strain at ultimate stress
1	72	2.031	77.963	0.028
2	72	2.113	87.135	0.031
3	72	1.119	49.013	0.032
4	72	2.259	111.593	0.036
5	72	1.319	55.128	0.030
means. ± stdvs.		1.768 ± 0.513	76.166 ± 25.291	0.031 ± 0.003

The results (Table 1, 2, and 3) show the alkaline treatment does not improve the mechanical properties of hemp yarns, it improves the surface of the hemp yarn, that helps reduce lignin, wax, and other contaminants, which potentially improves adhesive strength between the yarn and the polymer matrix of the composite. The alkaline treatment helps roughen the yarn surface; hence, the adhesion between the yarn and the matrix is better.

4. Conclusion

The presented detailed characterization of textile hemp yarn shows a number of findings, some of which are important in the prediction and interpretation of the properties of hemp yarn reinforce composites:

- The density of the hemp yarn is about 132.77 tex.
- The tensile properties of hemp yarn, apparent stiffness of the hemp yarns is in the range 0.5 – 7.5 GPa. This is much below the reported stiffness of single fibres, which is in the range 30 – 60 GPa[3]. The ultimate stress of the hemp yarns is in the range 30 – 330 MPa, and this is little below the range 350 – 300 MPa reported for single hemp fiber [3]. And strain at ultimate stress range 0.027 – 0.053.

References

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