



Chapter 2

Coir and Hop Fibres: Tensile Characterization and Comparison Between Fibres from Distinct Climates



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Abstract The human behaviour has significantly affected the climate. Because of that, the pursue of new alternatives for non-renewable materials has increased. In that scenario, the use of natural fibre to substitute synthetic ones in composite materials has also increased. In this work, two types of natural fibres from different regions and climates were evaluated and compared. The evaluated fibres were Coir from Brazil and Hop from Portugal and also were evaluated two different extraction methods for the hop batches, boiling in NaOH and maceration in water. To evaluate the composite mechanical characteristics, seven tensile tests were performed in each fibre batch, according to ASTM C 1557-14—Standard Test Method for Tensile Strength and Young’s Modulus of Fibres, and the average tensile strength for each one was calculated. The highest value of ultimate tensile strength was brought by the hop extracted with the boiling in NaOH method and resulted in an average of 16 MPa.

Keywords Green composite · Natural fibre composites · Tensile strength

2.1 Introduction

The effect of human behaviour on global changes is undeniable. The agenda of sustainable development has been widely in focus trying to find ways to continue with the socio-economic development in a more conscious way.

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At the beginning of the 1990s, the concept of Ecological footprint was developed by Mathis Wackernagel and William Rees, which measured the human demand on the biosphere (Wackernagel and Galli 2007). Since then, the global concern with carbon emissions and greenhouse effects has increased. In 1997, the Kyoto protocol was signed aiming to reduce the emission of greenhouse gases (Protocol 1998). All that leads to sustainable development and intense research targeting the use reduction of non-renewable materials, such as petroleum-based plastics and substituting them for renewable materials.

The challenge of substituting these materials is huge, that is why extensive research of natural sources is necessary. Nowadays, natural fibres are increasingly gaining space as an alternative to synthetic fibres and the technological development involved in the expansion of these materials is directly connected with consumers demands and expectations.

The use of natural plant fibres can be traced back more de 10.000 years. They were used about 8.000 B.C, in the Middle East and China, for textiles. In about 650 B.C., the Babylonians used it for burial purposes (Mwaikambo and Mwaikambo 2006), and over time, the plant fibres were always present.

Faruk et al. (Faruk et al. 2012) called this century the cellulosic century because of the vast number of renewable plant resources for products that are being discovered. The natural fibres are usually residues from primary processing of agricultural materials (Zhao et al. 2022), and all over the world, there is a huge variety of plant residues with potential to be used as natural fibres.

In addition to the growth region, other parameters have influence in the characteristics of the fibres, as the sowing time (Hall et al. 2013) and the sowing density (Bueno 2018), if there is an irrigation system. Many of these parameters are being explored, but the research still is a little restrict to some types of fibres that are more common, as flax (Graupner et al. 2021; Kandemir et al. 2021), hemp (Hall et al. 2013; Colomer-Romero et al. 2020), jute (Arulmurugan and Venkateshwaran 2019), sisal (Ekundayo 2019) and Coir (Tan et al. 2021; Bui et al. 2008; Majid 2011).

In industry, the natural fibres isolated have no huge application, so they are combined with different matrices to create composites. These can be polymeric matrices, cement matrices or other types that are being widely studied for different applications as natural fibre composites (NFC).

The NFCs already have a space in the commercial markets for value-added products, especially in the automotive sector. Although to achieve other markets, NFCs need to ensure high-quality performance, serviceability, durability and reliability standards (Faruk et al. 2012). That is why, the natural fibre research is increasing.

Some types of NFCs have already been widely studied and are already used in the industry, for example, the flax yarns that were accepted and established in the high-price segment and used in a hybrid composite with glass fibres used in prototypes of leaf springs of a narrow-gauge railroad (Graupner et al. 2021).

There are hemp fibres being studied for bio-composites with epoxy matrix, evaluating the difference between different epoxy resins (Colomer-Romero et al. 2020) and comparisons between different fibres and different weight percentages in the composites (Yun et al. 2022).

It is also used as an insulating material for the automobile industry, evaluating noise reduction, sound absorption, thermal resistance, biodegradability, antibacterial and antifungal characteristics. The use of light-weighted, green, environmentally friendly and biodegradable fibres as insulating materials provided comparable acoustic properties and thermal resistance with the commercial insulating materials (Cai et al. 2021). Hop bine fibres have already been used in the paper industry (Haunreiter et al. 2021). The coir fibre has been used for lightweight vehicle applications (Tan et al. 2021).

As seen before, natural fibres have a huge potential for usage, mainly as composite reinforcement. For that reason, this work aims to characterize different types of natural fibres in different regions of the world. The Coir was brought from Brazil and is also widely produced in India, which is the biggest producer in the world. The Hop was produced in Bragança, Portugal, but is also widely produced in many other countries such as the United States and Germany.

This work is proposed to characterize some mechanical properties of coir and hop natural fibres and compare the obtained results.

2.1.1 Natural Fibres

The natural fibres can be classified according to their sources. They can be animal fibres that are generally comprised of proteins. Mineral fibres are mainly occurring fibre or slightly modified fibre processed from minerals, or plant fibres that can be extracted from different parts of the plants, such as bast, leaf, seed, fruit or stalk (Saxena et al. 2011).

Coconut fibre/Coir. The coconut fibre, also called Coir, is extracted from the drupe of the coconut tree, *Cocos nucifera*, that is from the Palm family, *Arecaceae*. There are two types of coconut fibres, the brown and the white ones. The brown fibres are extracted from the mature coconut, and they are thick, are strong and have high abrasion resistance. The white fibres are extracted from the immature coconut, and they are smoother and finer than the brown ones but are also weaker (Ekundayo 2019). The coconut fibre is composed of hemicellulose, cellulose and lignin in percentages as shown in Table 2.1.

Hop fibre. The Hop fibre is extracted from the hop plant, *Humulus lupulus*, a member of the family *Cannabaceae*, the same as hemp. The Hop plant is mostly grown for its flower and after its harvesting the plant is cut and considered waste.

The Hop fibre is composed of cellulose, lignin and ash as shown in Table 2.2.

Table 2.1 Coir chemical composition (Faruk et al. 2012)

Fibre	Cellulose (wt%)	Hemicellulose (wt%)	Lignin (wt%)
Coir	32–43	0.15–0.25	40–45

Table 2.2 Hop chemical composition (Bredemann 1944)

Fibre	Cellulose (wt%)	Hemicellulose (wt%)	Lignin (wt%)
Hop	84 ± 1.6	6.0 ± 0.2	2.0 ± 0.1

2.2 Experimental Procedure

2.2.1 Hop Fibre Extraction Method

The hop fibres were extracted using two different methods, boiling in NaOH and maceration in water and were named Hop 1 and Hop 2, respectively.

The first method was based on Bredemann (Fiore et al. 2015) procedure. The fibres were extracted from random medium plants, with no distinguishment between what part of the bast was. The samples were boiled in a 0.35% NaOH solution for 1.5 h to separate the bark from the nucleus. Succeeding, the bark was boiled in a 2% NaOH solution, washed with tap water and dried at a temperature of 70 °C without any positioning of the fibre.

In the second method, the fibres were also extracted from random medium plants, with no distinguishment between what part of the bast was. The samples were submerged in water until the bark comes off. The water was renewed three times to reduce de Ph variation.

2.2.2 Specimen Manufacturing

The Coir was bought from a Brazilian industry that sells brown coconut fibres for gardening. The samples were untangled from the fibre tangles, Fig. 2.1. As the objective was to compare the two types of fibres, the coir was chosen to have almost the same thickness, 1 mm. After being chosen, they were cut 9 mm in length.

The samples of hop fibre, extracted as described before, also from tangles, Fig. 2.2, were also chosen to have thickness close to 1 mm and cut with 9 mm in length.

The fibres were weighted in a 4 decimal Laboratory Weighing Balance (ADA model 210/C). The mean masses are presented in Table 2.3.

After the mass evaluation, the samples were prepared for the tensile test. The samples were fixed in paper supports with masking tape, Fig. 2.3, according to ASTM C1557, and identified with LC for the first hop batch, LE for the second hop batch and C for the coir batch and numbers from 1 to 8. Figure 2.2 sample, for example, is the first sample of the second hop batch.

All the samples have the same gauge length, 4 mm.



Fig. 2.1 Coir tangled fibres



(a)



(b)

Fig. 2.2 a Hop 1 tangle, b Hop 2 tangle

Table 2.3 Mean masses, standard deviation

Sample	Mean mass (g)	σ
Coir	0.0170	0.004454
Hop 1	0.013825	0.003913
Hop 2	0.0048	0.00033



Fig. 2.3 Sample example

2.2.3 Tensile Test

After that, the samples were tested in a universal test machine, Shimadzu Autograph AGS-X 10Kn, with a constant deformation velocity of 5 mm/min.

For each batch were made 7 samples, tested following the ASTM C 1557-14—Standard Test Method for Tensile Strength and Young's Modulus of Fibres.

2.3 Results and Discussion

The test machine returned the displacement in millimetres, the force in newtons and the time in seconds. With this information and the gauge length, the stress and strain were calculated. The graphs were plotted and are presented in Figs. 2.4, 2.5 and 2.6.

The significant variability of the results between the samples of the same batches is due to the difficulty of tensile testing on single lignocellulosic fibres. Many factors have influence in the results, as test parameters and conditions, plant characteristics as the source and age of the plant, the processes of fibre extraction and the presence of defects (Fiore et al. 2015; Liu et al. 2009). As some of these parameters could not be controlled, it is not possible to determine what is the source of the variation.

To compare the behaviour between the three batches the average stress–strain curve was determined for each material. In Fig. 2.7 is presented a comparison between the three average stress–strain curves.

Based on the stress–strain curves, Young's modulus was calculated for each sample and its values and standard deviation are presented in Table 2.4.

The values of the Coir Young's modulus are considerably smaller than the values that are seen in the literatures, that are around 4–6 GPa (Majid 2011; Biswas et al. 2013). In these works, the researchers had control in the extraction method, something that was not possible here because the fibres were bought already extracted.

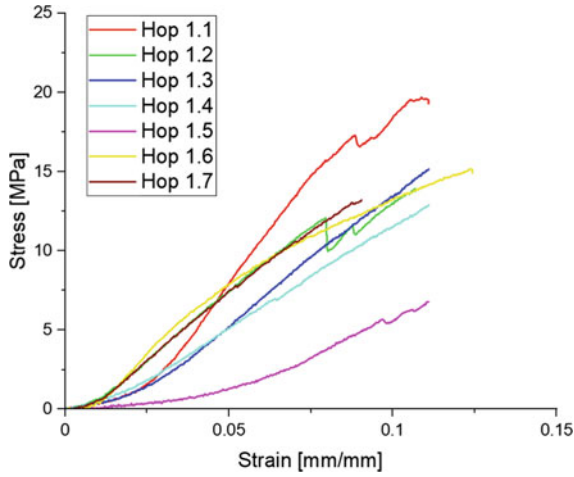


Fig. 2.4 Hop 1: stress versus strain

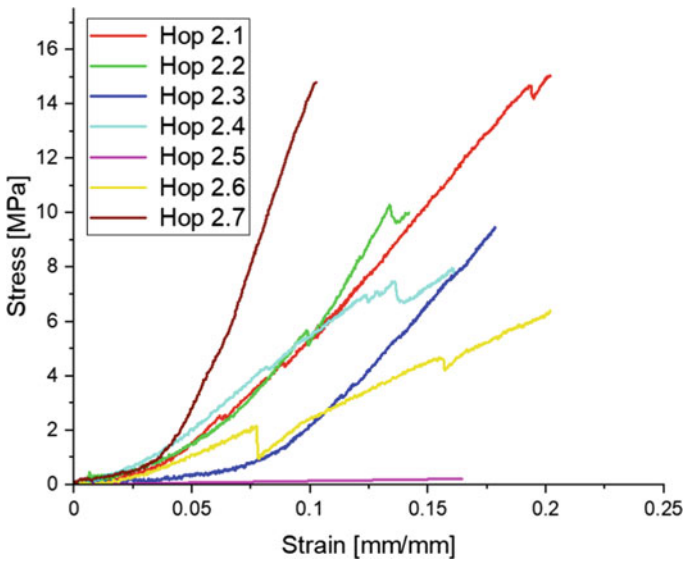


Fig. 2.5 Hop 2: stress versus strain

The exact extraction method that was used to these fibres is not known. These fibres were bought from a gardening supply's company so, probably the integrity of the fibre was not the main concern in the extraction. This is one of the possible explanations for the difference in Young's modulus.

Fig. 2.6 Coir: stress versus strain

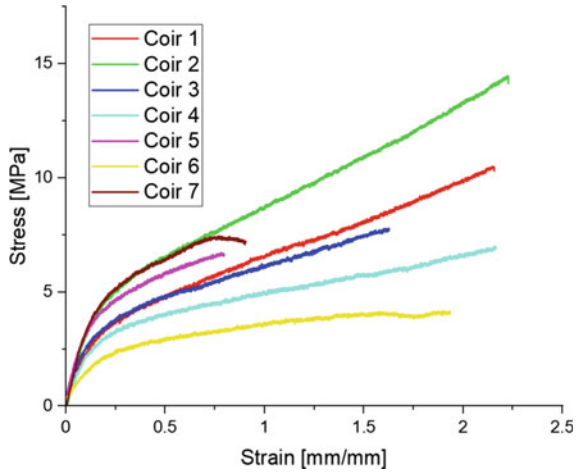


Fig. 2.7 Comparison: stress versus strain (average)

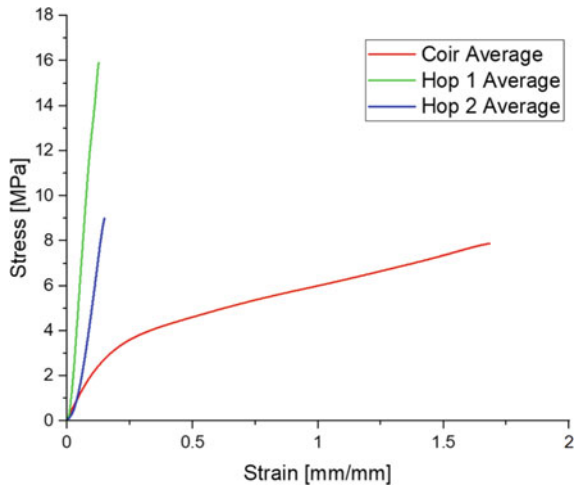


Table 2.4 Young’s modulus and standard deviation

Sample	Young’s modulus (MPa)	σ
Coir	40.5	8.6
Hop 1	16.1	5.8
Hop 2	30.8	3.9

Also, with the graphs, the force to failure was extracted for each sample and it is presented in Table 2.5 with its standard deviation.

Table 2.5 Ultimate tensile strength and standard deviation

Sample	Ultimate tensile strength (MPa)	σ
Coir	7.90	1.98
Hop 1	16.00	3.23
Hop 2	9.03	4.71

As seen in the results, the standard deviation was very high for the hop fibres batches, and it is due to the difficulty of tensile test on single lignocellulosic fibres, as explained before.

It was expected that the results for the hop fibre batches would be similar to the results for hemp and cotton fibres (Reddy and Yang 2009), but they were considerably different. The difference may possibly be because of the lack of distinguishment between what part of the bast was, causing a considerable variation in the results between samples and the expected results.

Combined with that, both batches of the hop fibres were not positioned in an aligned way for the drying process. They were tangled, as shown in Figs. 2.1 and 2.2, so when the samples were extracted only the strongest fibres were in conditions to be used in the test, the fibres that were thinner or had any type of defect could not even be aligned to be fixed in the test supports.

In the coir fibre samples, these problems were not seen. But many coir samples fractured near or in the gripping area which may be because of the fragilization of the extraction method or because of fragilization generated by the gripping method.

2.4 Conclusions

These are preliminary results for the use and comparison of these two fibre types. There are already many studies with the coir, but the use of the hop fibres has not been profoundly investigated. At the beginning of this research, the results are satisfactory and the major conclusion that can be assumed is that the extraction method must be improved to generate samples more standardized.

To have greater conclusions the tests have to be repeated making improvements in the fibre's extraction methods and controlling the other parameters to understand which parameters interfere the most in the test results.

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