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Extraction of natural fibers for the manufacture of 3D filaments by FDM material extrusion

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ABSTRACT

The study aimed to extract hemp fibers for the NaturFab project, in order to mechanically strengthen PLA in filaments for 3D printing. In order to find the best extraction method, several chemical treatments were carried out to separate the fibers from the plant, using solutions of 2 g/l of sodium hydroxide (NaOH) + 2 g/l of sodium carbonate ($NaCO_3$) and another solution of 6% NaOH, both at 80 ºC. After obtaining the first fiber sample, tensile tests were carried out to compare the strength of the hemp fibers with those of commercial flax. Hemp showed inferior performance compared to flax fibers, with a more fragile behavior after treatment with 6% NaOH. However, a solution of NaOH and $NaCO_3$ with polyglycolic detergent facilitated extraction and improved fiber strength, but further tests should be carried out to verify its effectiveness.

Keywords: Hemp Fiber Extraction; Chemical Treatments; PLA Reinforcement; Tensile Strength.

CONTEXT

The following study was carried out with the aim of obtaining hemp fibers for the NaturFab project, which seeks to incorporate them into 3D printing filaments to increase the mechanical strength of PLA, as observed in the study carried out by (Deb & Jafferson, 2021).

In this work, different chemical treatments were carried out to obtain the fibers, seeking to identify the best way to remove the fibers from the hemp plants.

MATERIAL & METHODS

This topic discusses the methods used to obtain natural fibers for incorporation into 3D printing filaments.

Obtaining the hemp for the experiments

In order to obtain the hemp fibers, the plants that were grown as shown in figure 1 were harvested and left to dry in the environment for 36 days in the case of Date 1 and 30 days in the case of Date 4, as shown in table 1. The variations Date 1 to 4 refer to the planting dates of the samples, with Date 1 being the oldest and Date 4 the most recent.

Figure 1 - IPB hemp plantation.

Table 1 - Planting, harvesting and experiment dates.

Variation	Planting	Harvesting	Experiment
Date 1	21/may	13/aug	18/sep
Date 2	03/jun	13/aug	-
Date 3	18/jun	19/aug	-
Date 4	02/jul	19/aug	18/sep

Chemical treatments applied to hemp

To obtain hemp fiber, two different chemical treatments were applied. In the first, a 6% solution of sodium hydroxide (NaOH) was used, which was heated to 80 ºC; after reaching this temperature, the plant was immersed and left for half an hour to assess the progress of the decomposition of lignin and hemicellulose that causes the fibers to loosen, similar to the processes seen in (Deb & Jafferson, 2021), (Paulo, Santos, Rocha, Lima, & Ribeiro, 2023) In the second treatment, the samples were immersed in a solution of 2g/l of sodium carbonate (NaCO3) and 2g/l of sodium hydroxide (NaOH) also heated to 80 ºC (Figure 2) for half an hour, similar to that carried out in (Mariz, 2023), in order to compare progress.

Figure 2 - Equipment used to heat the solution.

After the chemical treatments, all the samples were left to dry in a hotte with the ventilation on for a period of 24 hours, as shown in Figure 3.

Figure 3 - Samples drying in the chapel.

The samples were then analyzed to see which had the most effective result in terms of obtaining fibers. Once the best sample had been identified, the experiment was repeated with the same solution at 80 ºC, leaving it immersed for 24 hours and drying it before removing the fibers.

Mechanical tests applied to the fibers

After obtaining the fiber, a tensile test was carried out on samples of hemp fiber obtained through chemical treatment and flax fiber obtained commercially. The test parameters were similar to those used in the study in (Ribeiro, Bueno, Martin, & Rocha, 2023) with a test speed of 3 mm/min.

To attach the fibers to the jaws of the test machine, cards were cut out on which the fibers were glued, as shown in Figures 4 and 5, thus preventing the fibers from breaking or slipping when they were attached. After placing the card with the fiber in the machine's jaws, the sides of the card were cut so that the polymer would not interfere with the test results.

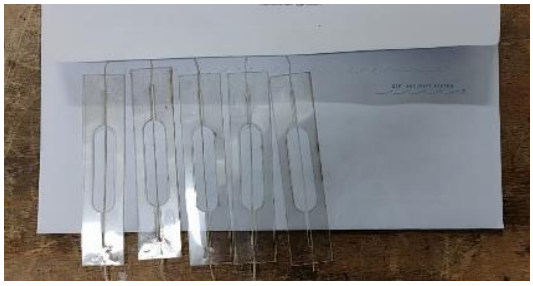

Figure 4 - Prepared flax samples.

Figure 5 - Prepared hemp simples.

RESULTS AND DISCUSSIONS

This section will present the results of the experiments carried out to obtain the natural fibers, as well as the tests carried out to compare them with commercially obtained flax.

Obtaining the hemp fibers

The Data 1 and Data 4 hemp samples were placed in solutions of 6% sodium hydroxide (NaOH) and a mixture of 2g/l sodium carbonate (NaCO3) and 2g/l sodium hydroxide (NaOH). After a period of 30 minutes at 80 ºC, the samples were removed and the results shown in Figures 6, 7, 8 and 9 were obtained.

Figure 6 - Hemp Date 1 6% NaOH 30 minutes.

Figure 7 - Hemp Date 1 2 g/l NaOH + 2 g/l NaCO3 30 minutes.

Figure 8 - Hemp Date 4 6% NaOH 30 minutes.

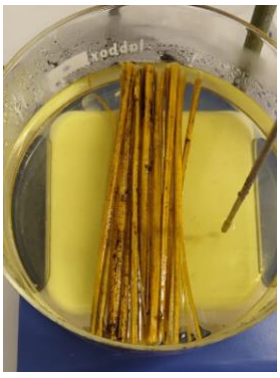

Figure 9 - Hemp Date 4 2 g/l NaOH + 2 g/l NaCO3 30 minutes.

All samples were subsequently dried under controlled airflow conditions for 24 hours. Following this drying phase, it was observed that the sample treated with sodium hydroxide, labeled as Data 1, demonstrated the highest fiber detachment potential. With the identification of the most effective sample and solution, an additional experiment was conducted at 80ºC for 24 hours. This procedure yielded a result that successfully facilitated fiber extraction, as illustrated in Figure 10.

Figure 10 - First fiber sample taken from Date 1.

Following fiber extraction, hemp fiber samples and commercially sourced flax fiber samples were prepared and subjected to tensile strength testing. The results indicated that the hemp fibers exhibited significantly lower tensile strength compared to the flax fibers, as illustrated in Figure 10.

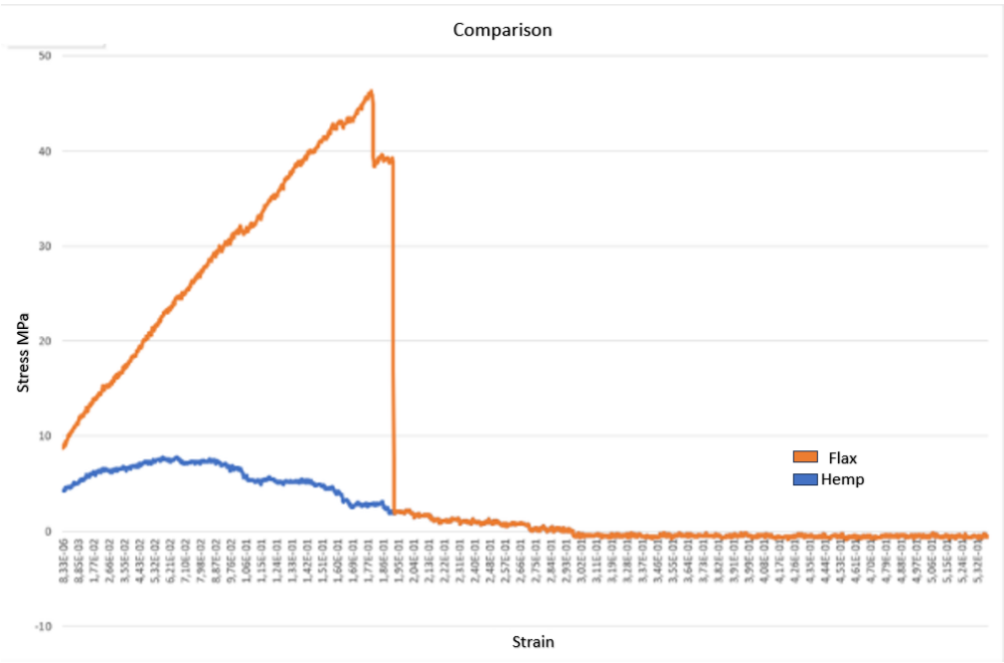

Figure 10 – Comparison of flax and hemp.

After the initial tests, a new experiment was conducted in which the plant materials were immersed for 5 hours in a solution containing 2 g/L NaOH, 2 g/L Na_2CO_3, and 0.5 mL/L polyglycolic ether detergent at 80ºC. In this modified experiment, the fibers separated more readily compared to previous trials and exhibited a less brittle texture.

CONCLUSIONS

The initial experiments did not yield fibers with satisfactory performance characteristics when using the solutions applied. Specifically, the 6% sodium hydroxide solution weakened the hemp fibers. Additionally, because the plants were already dry, the hydration process was slower, and the lignin adhered more firmly to the fibers after drying, complicating the fiber extraction process.

The solution containing 2 g/L NaOH, 2 g/L Na_2CO_3, and 0.5 mL/L polyglycolic ether detergent was more effective in facilitating fiber extraction. With this solution, fibers were obtained in a shorter time and displayed a less brittle texture. However, to verify the mechanical robustness of these fibers, further comparative tensile strength tests are required.

Future studies could benefit from exploring alternative methods for hemp fiber extraction, including both mechanical and biological approaches. Such approaches, already investigated by other researchers for extracting various natural fibers, may provide improved fiber quality and performance characteristics.

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