Journal of
Composites Science

MDPI

Article

Fabrication and Characterization of Hybrid Bio-Composites Using Braided Natural Fibers and Aligned Thermoplastic Filaments

Akhilesh Kumar Thakur *, Jens Schuster and Yousuf Pasha Shaik

Department of Applied Logistics and Polymer Sciences, University of Applied Sciences Kaiserslautern, 66953 Pirmasens, Germany
* Correspondence: akth1001@stud.hs-kl.de

Abstract: The composite group investigates endlessly the features of natural fiber/thermoplastic matrix composite materials to improve recyclability, use of renewable sources, and reduce material costs. In this context, the development and use of biodegradable polymers for composites is considered one of the important strategies for reducing environmental challenges. Here, axially oriented fibers incorporated in conforming matrices make up fiber-reinforced composites. Due to the high viscosity of molten Poly(ε-caprolactone) (PCL), impregnating into reinforced fiber strands is challenging. So, continuous hybrid flax and hemp fibers were produced using a braiding technique by considering the fiber aspect ratio (AR). The resulting braided yarns were parallel aligned with PCL filaments before being compression molded into unidirectional composite laminates. The flax and PCL blend had better mechanical properties than the other produced composites. Temperatures for the glass transition, melting, and crystallization, were much greater than for neat PCL. However, mechanical properties were barely altered due to the ductile nature of PCL.

Keywords: bio composites; hemp fiber; flax fiber; polycaprolactone; braiding; compression molding

check for updates

Citation: Thakur, A.K.; Schuster, J.; Shaik, Y.P. Fabrication and Characterization of Hybrid Bio-Composites Using Braided Natural Fibers and Aligned Thermoplastic Filaments. *J. Compos. Sci.* **2022**, *6*, 291. https://doi.org/10.3390/jcs6100291

Academic Editor: Francesco Tornabene

Received: 30 August 2022
Accepted: 29 September 2022
Published: 2 October 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Over the past years, fiber-reinforced composites (FRC) have emerged as preferable substitutes to a variety of conventional materials due to their improved structural and mechanical qualities. Creating materials with high strength and increased elastic modulus is the main goal of fiber-reinforced composites. However, natural fiber composites have several distinctive technological characteristics that set them apart from glass and carbon fiber composites. Epoxy, vinyl ester, and polyester, are common conventional polymer matrices for a variety of structural applications because they have superior mechanical characteristics to biodegradable polymers. These polymers, however, cannot be recycled and cannot degrade naturally, and as a result, they have a negative impact on the environment [1]. A recent study has aided in the development of hybrid composites that combine natural and synthetic fibers. Fiber hybridization is a potential method, which combines two or more forms of fiber in a matrix of composite material to reduce the shortcomings of one type of fiber while retaining the advantages of another [2]. Hybrid polymer composites are being utilized often due to their exceptional qualities. Abdelkader et al. [3] proposed a novel technology for producing dental posts that are compatible with this purpose by braiding glass fibers and thermoplastic fibers. Posts are created with the use of a braiding machine, and braids are then put into an aluminum mold.

One of the more commonly utilized hydrophobic polymers in everyday life is PCL, which is employed in applications such as packaging and electronics [4]. In terms of specific stiffness, flax and hemp composites outperform glass fiber composites in both tension and bending, and they only slightly lag behind carbon fiber composites in bending. Furthermore, flax and hemp fibers have a far better vibration dampening capacity, which makes

them ideal for use in athletic goods or musical instruments [5]. Numerous variables affect the characteristics of fiber-reinforced composites, such as the matrices and reinforcement employed, the fiber volume fraction, the fiber aspect ratio, the fiber diameters, and the interfacial bonding between the reinforcement and the matrix [6]. Melenka et al. [7] had given an overview about the different types of manufacturing processes for braided composite materials and also variables, kinematics required for manufacturing. The competence of each production process in relation to the desired product must be carefully considered when choosing braiding as a process. Tensile strength and Young's modulus drop with maximizing braid angle, while 45° is ideal for braided tubes and filament-wound tubes under torsion.

S. Kobayashi et al. [8] fabricated continuous hemp fiber reinforced PLA composites using a micro-braiding process followed by hot press molding. Hemp fiber and matrix were thermally disintegrated at molding temperatures of more than 210 °C. Due to improved impregnation and the contraction of the fiber's lumen, porosity lowers as molding temperature rises. Porosity is caused by a lack of interfacial contact, which stimulates moisture absorption. Porosity in natural fiber composites is challenging to prevent and affects the quality of the composite, but little research has been done on how to regulate it. Y. Chai et al. [9] presented key information about the layout of braid architecture for torsional loaded components. Malinowski, R et al. [10] processed hemp fibers reinforced PCL composites using a twin screw extrusion process, which is modified by electron beam irradiation. It was encountered that modified PCL with hemp fibers and electron radiation had increased flexural modulus but lowered impact strength and elongation at break. It was found that the tensile behavior and crystallinity of the neat PCL matrix were significantly improved by the addition of ramie and Borassus fibers [11]. Alkali treatment enhanced the interfacial adhesion in PLA/hemp fibers, which is required to minimize interfacial seeping of the water molecules. As a result, chemical treatments can lessen the composites' moisture absorption [12]. The effect of alkali treatment has improved the tensile and hardness properties of uniaxially-oriented intimately mixed kapok/glass fabric-reinforced polyester hybrid composites [13].

Various modification techniques have assisted in enhancing the mechanical and thermal properties of bio composites. Unidirectional hemp fibers clearly boost the reinforced matrix's mechanical characteristics in terms of tensile strength and hardness. However, these composites continued to have serious problems with poor fiber-to-matrix adhesion and unequal fiber dispersion throughout the matrix [14,15]. The applied load passing from the matrix to the fibers, the interfacial connection between the fiber and matrix, their relative alignment, and the nature of the fiber scheming the overall material characteristics all have an impact on the strength elevation. However, depending on the final uses, the fiber alignment may be random or continuous. The application's requirements also influence the selection of the fiber reinforcement and its fitting matrix [16].

In this perspective, the development and usage of biodegradable polymers for composites is seen as one of the critical techniques for mitigating the environmental risks associated with the use of petroleum-based and non-biodegradable polymers. Braiding techniques were used in the current work to braid hemp and flax fibers, and composite synthesis was accomplished through the melting process. The peculiar technique outlined in this research makes use of parallelly aligned thermoplastic filaments to take advantage of their various benefits, including low melting points and the simplicity of manufacture.

2. Materials and Methods

2.1. Materials

Poly(ε-caprolactone) (PCL) is a semi-crystalline, biodegradable, non-cytotoxic polyester with a molecular weight of 80 kg/mol, and was utilized as a matrix for impregnation. It has a relatively low melting point of 65 °C with a filament diameter of 1.75 mm and arelative density of 1.145 g/cm^3, which was ordered from eSUN Filaments, The Netherlands. Two types of fibers were used in this process: hemp and flax fibers. These fibers were kindly

supplied by Etsy GmbH, Germany. According to the supplier, hemp fibers had a linear density of 142 Tex, the relative density of 1.47 g/cm^3 and unbleached with 100% cellulose, while flax fibers had a linear density of 137 Tex, the relative density of 1.54 g/cm^3 and unbleached with 100% linen. Hemp and flax fiber had average mean diameters of 125 µm and 175 µm, respectively. A 2 wt% solution of NaOH was provided by Carl Roth GmbH, Karlsruhe, Germany.

2.2. Methods

2.2.1. Alkali Treatment

The alkali treatment promotes the mechanical properties of the fiber, which contributes to the enhancement of the composites' physical characteristics. Eliminating hemicelluloses from the fiber may help the fibrils align themselves with the direction of tensile pressures, improving load distribution. Due to the elimination of noncellulosic components that cover the cellulose hydroxyl groups, alkali treatment improves the efficiency of accessible hydroxyl groups. The surface of the fiber is also cleaned of contaminants, revealing a clean, rough surface with numerous pits that will significantly enhance the surface area of the fiber. Increased surface roughness would allow for improved mechanical interaction with PCL in addition to increasing the number of hydroxyl groups for hydrogen bonding. To get rid of the soluble oily elements, the needed amount of hemp and flax fibers were treated with a 2 wt% solution of NaOH for 30 min. The surplus NaOH was then completely rinsed out of the fibers with water. The fibers were then allowed to dry at room temperature for 24 h before being reinforced.

2.2.2. Braiding

Braiding of alkali-treated hemp and flax fibers was performed on a braiding machine (Model Murata 97sx339060) from Murata Machinery Ltd., Kyoto, Japan. Figure 1 shows the arrangement of alkalized fiber spools on the braiding machine. When the carriers are rotated, fiber spools start braiding. The braided fiber was being pulled by hand manually and wound on another spool. When comparing the two different hybrid yarn manufacturing processes, braided yarn was found to perform better than co-wrapped yarn with an identical flax/PP mass ratio [17]. Fibrous-shaped braided yarns were created using four fiber spools. The fiber orientation angle, the set of fiber spools used to create the braided yarn, and the number of fiber yarns, all influence the braided yarn's dimensions. By considering these parameters, yarns with a braid angle of 45° and angular velocity(ω) of 50 rad/s are produced. Braided flax fibers are shown in Figure 2a using optical microscopy, whereas diamond braid (1/1) fibers are depicted in Figure 2b. Here, three different types of braided yarns are produced, as shown in Table 1.

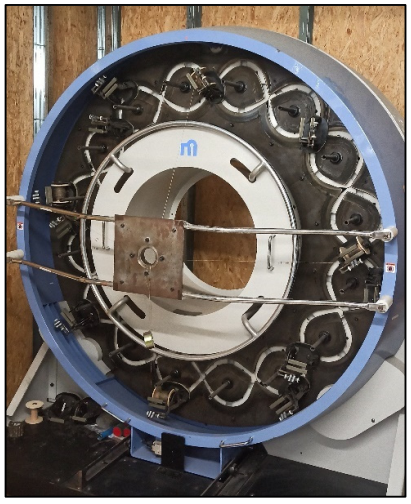


Figure 1. Arrangement of fiber spools on braiding machine.

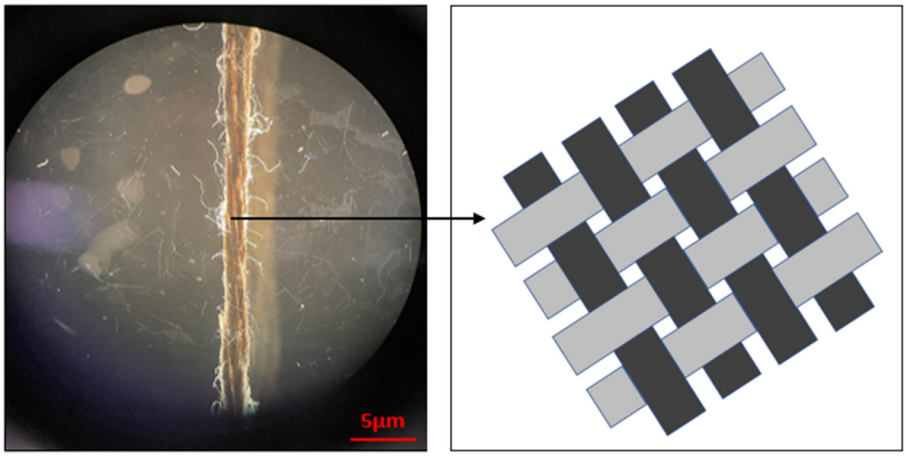


Figure 2. (**a**) Optical microscopy image of braided flax fibers, (**b**) schematic view of fibers representing diamond braid (1/1).

Table 1. Different types of braided yarns.

Types of Braided Yarns	No. of Hemp Fibers	No. of Flax Fibers
1.	4	0
2.	0	4
3.	2	2

2.2.3. Compression Molding

The compression molding of the samples was conducted on a hot press machine (Model Collin P 200 P) from Dr. Collin GmbH, Germany. The laminates were prepared by placing braided yarns and PCL filaments inside the mold. The molding temperature was maintained at 65 °C and pressure at about 3 MPa. The holding time to obtain laminates was kept up to 15 min. An air-cooling system is being employed for cooling the laminates. Later, obtained laminates were cut into desired sample dimensions for testing.

2.3. Sample Preparation

A braiding approach was utilized to provide the variable material design on continuous fiber reinforced thermoplastic composites in terms of enhancing the impregnation of thermoplastic resin into fiber yarns. As the reinforcing fibers and matrix filaments are aligned, high matrix impregnation and fiber dispersion can be expected. Additionally, this approach enables simultaneous shape formation and impregnation for diverse thermoplastic matrices [18]. Alkali-treated hemp and flax fiber braided yarns were wound on different spools. These yarns were cut and placed axially in an aluminum mold. A gap of 10–15 mm existed between each braided yarn. Thus, five braided yarns were retained inside the mold. The aspect ratio has a significant impact on the mechanical and thermal properties of composite materials [19]. The fiber aspect ratio (l/d) is the ratio of mean fiber length to diameter in mm. Different ARs were used for the production of tensile and Charpy samples. The diameters of hemp, flax, and combined hemp and flax fibers at 0.6, 0.8, and, 0.7 mm, respectively. Figure 3 shows a flowchart summarizing the steps involved in manufacturing hybrid bio-composites. The viscosity of thermoplastic polymers varies significantly with changes in temperature, density, and shear rate The relative density of the PCL filaments is 1.145 g/cm^3, which is quite high. Melt flow rate also majorly effects the viscosity of the matrix during fabrication process. Usually, the melt flow index (MFI) of PCL is in range of 6 ± 0.4 g/10 min at 100 °C.

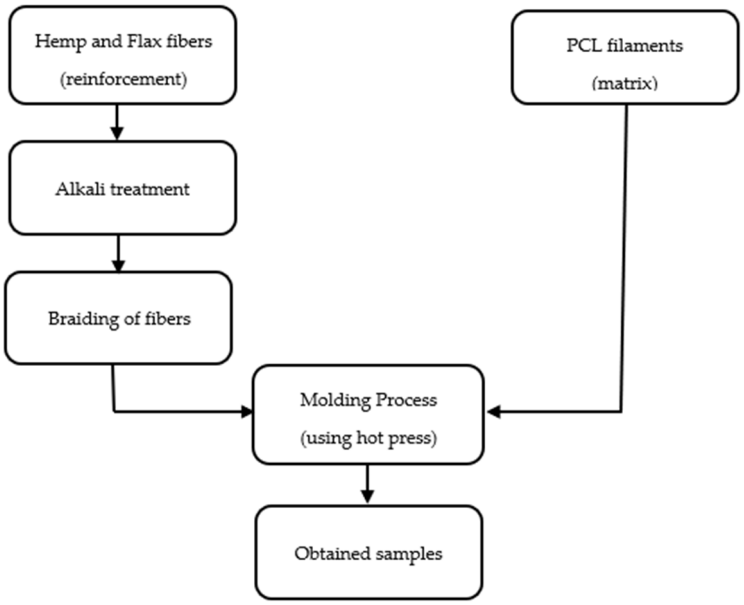


Figure 3. Flow chart for the process used in fabricating bio composites.

So, the required number of PCL filaments were cut, parallel to the braided yarns, and inserted between each yarn inside the mold, since it is challenging to saturate the thermoplastic matrix into lengthy fiber yarns.

Braided yarns along with filaments were compression molded to obtain laminates using a hot press machine at 65 °C and 3 MPa pressure for 15 min. To complete the solidification process, the mold was kept undisturbed for 40 min inside the press at released pressure. The mold was cooled through the airflow. Thus, there is only one heating phase, which prevents thermal degradation of the fiber and matrix and lowers the energy needed for molding. It is expected that the issues of impregnation when utilizing thermoplastic polymers in long-fiber reinforcements would be resolved due to the interaction between the reinforcing fibers and the parallelly oriented matrix.

Using this process, four different types of laminates are fabricated as shown below in Tables 2 and 3. Later, a cutting machine was utilized to cut the obtained laminates into samples for mechanical testing, and finally, all their properties were compared with respect to neat PCL.

Table 2. Types of samples produced for tensile testing.

Type of the Sample	Braid Diameter (mm)	Braid Weight (mg)	Sample Dimensions (mm)			Fiber Aspect Ratio (l/d)
			Length	Width	Thickness	
Hemp+PCL	0.6	916	120	10	4	200
Flax+PCL	0.8	1403	120	10	4	150
Hemp+flax+PCL	0.7	1412	120	10	4	171.42
Neat PCL	-	-	120	10	4	-

Table 3. Types of samples produced for Charpy impact testing.

Type of the Sample	Braid Diameter (mm)	Braid Weight (mg)	Sample Dimensions (mm)			Fiber Aspect Ratio (l/d)
			Length	Width	Thickness	
Hemp+PCL	0.6	602	80	10	4	133.33
Flax+PCL	0.8	835	80	10	4	100
Hemp+flax+PCL	0.7	813	80	10	4	114.28
Neat PCL	-	-	80	10	4	-

2.4. Experimental Setup

2.4.1. Tensile Tests

A Zwick Universal Testing Machine with a maximum force of 20 kN and speed of 5 mm/min was used to conduct the mechanical tests according to DIN ISO 527. The specimens for the tensile test have dimensions of (120 × 10 × 4) mm. For tensile testing, aspect ratios of 200, 150, and 171.42, were used for hemp, flax, and combined hemp and flax samples, respectively, by keeping the fiber lengths inside the mold for the various types of braid at 120 mm. The average value is considered after testing a total of 10 samples.

2.4.2. Charpy Impact Tests

The Charpy impact test, in accordance with DIN ISO 179, evaluates the proportion of energy that is absorbed by the component when it is confined to an impacting force to determine the impact strength. The impact test was conducted using a RayRan Advanced Universal Pendulum, from Ray-Ran Test Equipment Ltd, Warwickshire, UK. with 4-joule impact energy, a hammer weight of 0.9510 kg, and an impact velocity of 2.9 m/s. The impact strength of a fractured material is evaluated using an unnotched specimen. In this test, a testing sample is held in position while the pendulum arm is pounded with a hammer. Here, ARs of 133.33, 100, and 114.28, were used for hemp, flax, and combined hemp and flax samples, respectively, by keeping the fiber lengths for different types of braid at 80 mm. Specimens for the impact test were cut in dimensions of (80 × 10 × 4) mm. It is measured in units kJ/m^2.

2.4.3. Shore Hardness Test

Shore hardness is measured according to the standard DIN 53505, using a versatile testing device named Zwick durometer from ZwickRoell GmbH & Co. KG, Ulm, Germany. Shore D type is used to calculate the hardness value for thermoplastic and elastomer materials. The indentation depth shown on a gauge is a measure of the hardness. It has a cone-shaped indenter with a tip that can test hardness values between 30 and 90 shore. The device's top is loaded with a 50 N force. Within 5 s of the tip penetrating the specimen, the shore hardness measurement is recorded. Each specimen is measured at five different spots, which are a minimum of 5 mm apart from each other.

2.4.4. Differential Scanning Calorimetry (DSC)

In compliance with DIN EN ISO 11375-4, DSC testing was carried out using a Perkin Elmer DSC 7 from PerkinElmer LAS GmbH, Rodgau, Germany. In aluminum pans, (8–12) mg samples were weighed and sealed. On the test side of the DSC, sealed pans were placed and heated at a rate of 10 °C/min from room temperature 25 °C to a specified temperature based on the type of sample. The melting (Tm), glass transition (Tg), and crystallization temperatures (Tc), were evaluated.

Samples containing fibers were heated from 25 to 210 °C and maintained there for 5 min to attain full melting and get rid of any remaining anisotropy for the isothermal crystallization studies. The samples were then cooled from 210 °C to room temperature. Samples were once again heated to 210 °C. To finish the crystallization process, samples were cooled to room temperature until there was no longer any heat flow. The rate of heat flow was kept constant at 10 °C/min for all steps. For the neat PCL samples, the same steps were followed except the maximum temperature was kept at 80 °C and the heat flow rate was 5 °C/min. The analysis was conducted three times for each sample. For each sample, the first cooling run provided the crystallization temperature (Tc), whereas the second heating run provided the melting temperature (Tm) and glass transition temperature (Tg).

3. Results

3.1. Tensile Test

The test was performed at a 5 mm/min speed. A gap of 80 mm was kept between the two grips. Figure 4a shows a batch of test samples that were tested. Figures 5 and 6

illustrate the outcomes for each type of set. Graphs were drawn in accordance with the average of the sample test findings. The tensile modulus of flax + PCL was relatively high in comparison to other samples. The test results show that tensile modulus improved by 127.12% compared to neat PCL upon the addition of alkalized braided yarns.

The maximum load that a sample can withstand is outlined by the yield strength criterion. Combined hemp + flax + PCL showed an improvement of 57.4% yield strength in contrast to neat PCL. However, yield strain results of different samples were in proportionate to neat PCL.

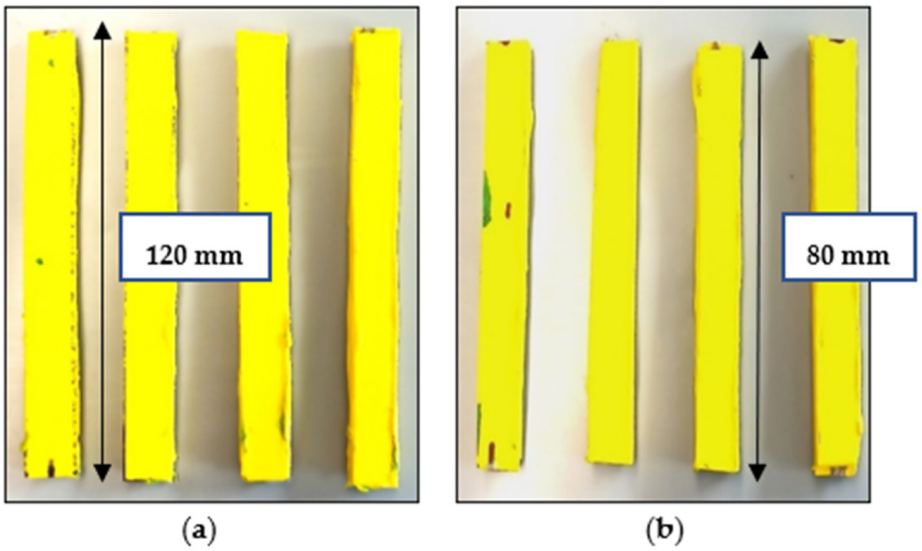


Figure 4. Compression molded samples with axially aligned fibers: (**a**) for tensile test, and (**b**) for Charpy test.

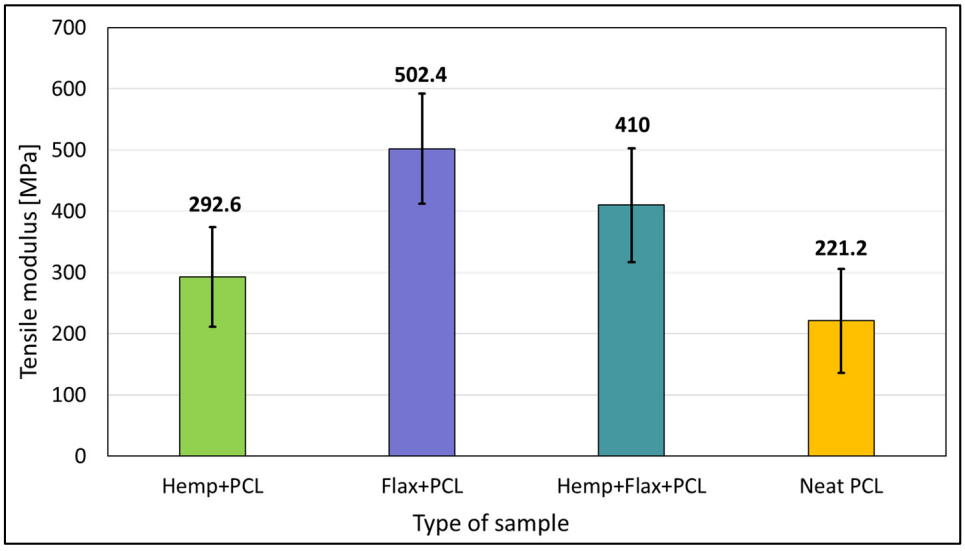


Figure 5. Tensile modulus comparison of different samples.

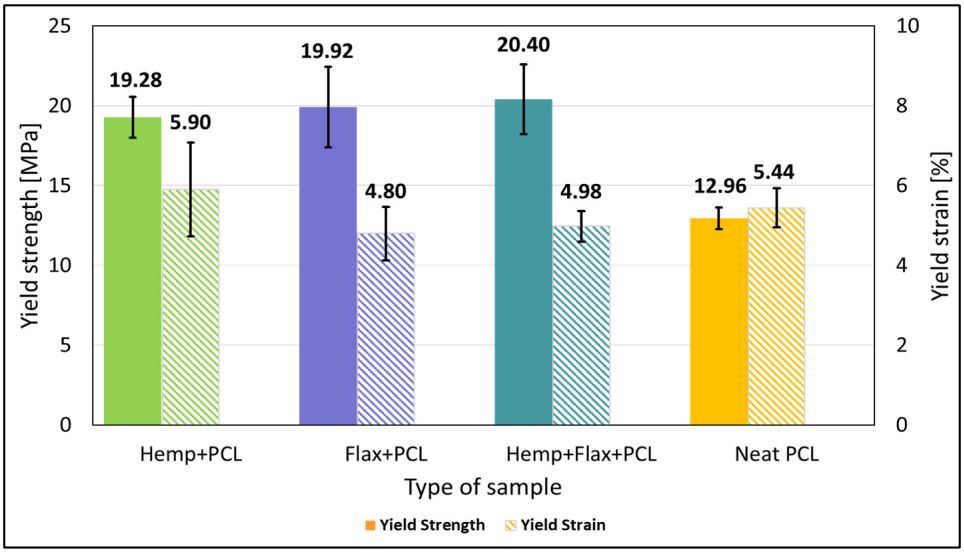


Figure 6. Yield strength and yield strain comparison of different samples.

3.2. Charpy Impact Test

The impact strength of the fiber combined samples significantly increased as shown in Figure 7. Figure 4b shows a batch of test samples that were used for impact testing. Flax + PCL exhibited the highest impact strength with an improvement of 64.14% compared to neat PCL.

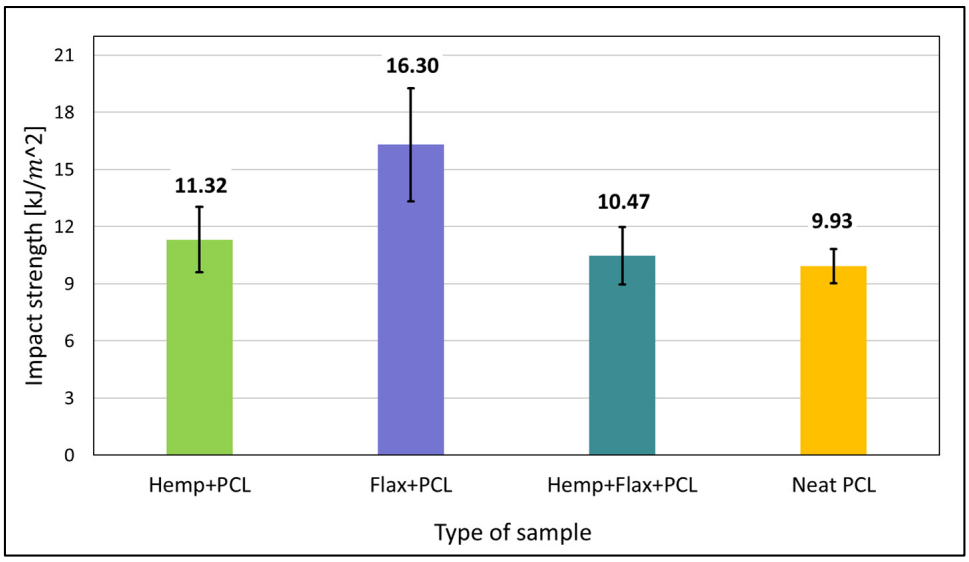


Figure 7. Impact strength comparison of different samples.

3.3. Shore Hardness Test

The Shore hardness value is slightly increased as shown in Figure 8. The addition of braided yarns showed a significant improvement in hardness. The cone-shaped indenter with a tip was placed at the center of the sample i.e., above the impregnated yarn while testing. Combined hemp+flax+PCL outlined the highest hardness value with an improvement of 8.12%.

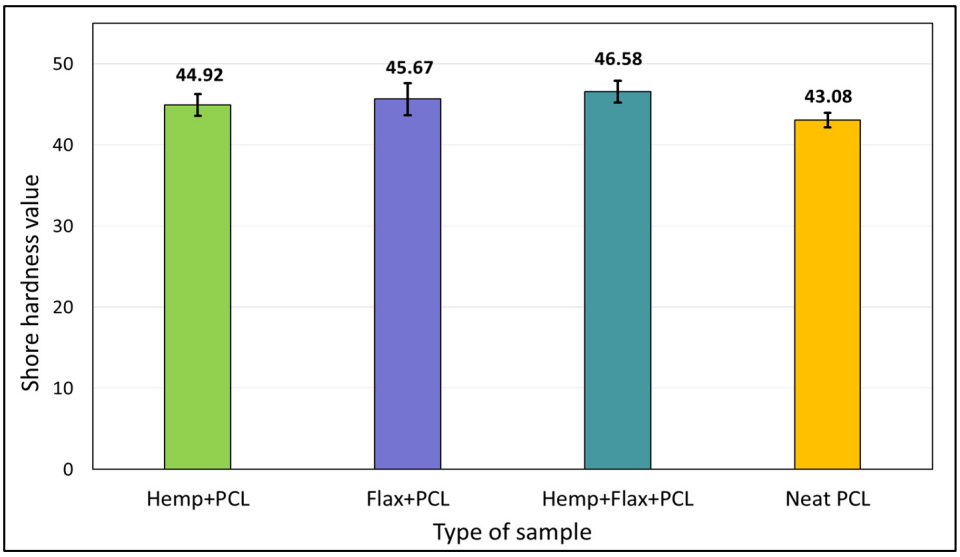


Figure 8. Shore hardness comparison of different samples.

3.4. Differential Scanning Calorimetry (DSC)

DSC heating and cooling curves of PCL and its composites containing different fibers are reported as shown in Figures 9 and 10. Figure 11 provides the calculated PCL and its composites glass transition temperatures (Tg), melting temperatures (Tm), and crystallization temperatures (Tc), based on DSC thermograms. Combined hemp + flax + PCL reported the highest thermal values when compared to others. The presence of cellulosic fibers induced a tremendous improvement in crystallization temperatures, glass transition temperatures, and the melting temperatures of samples.

The crystallization temperature of hybrid composite were increased by 275.02%, whereas the melting temperature was by 240.26%. The glass transition temperature almost remained the same for all fiber-induced samples.

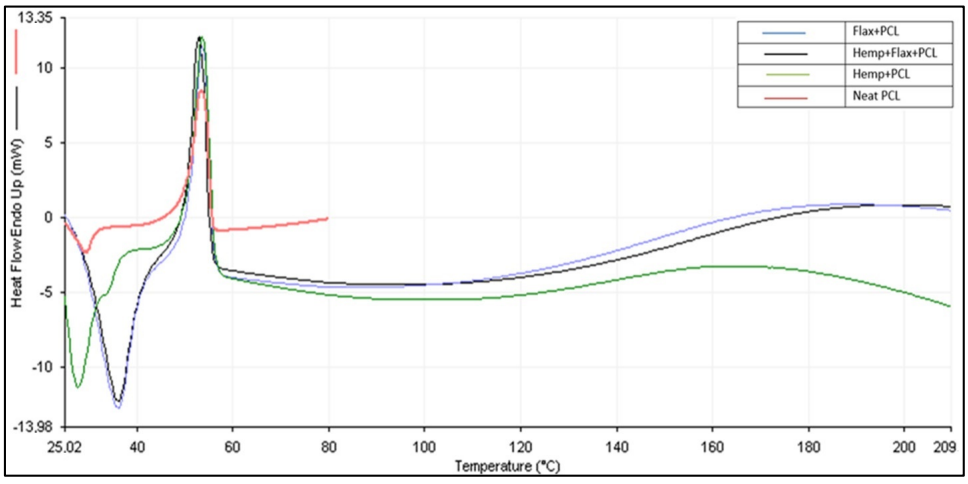


Figure 9. DSC curves representing Tg and Tm of different samples.

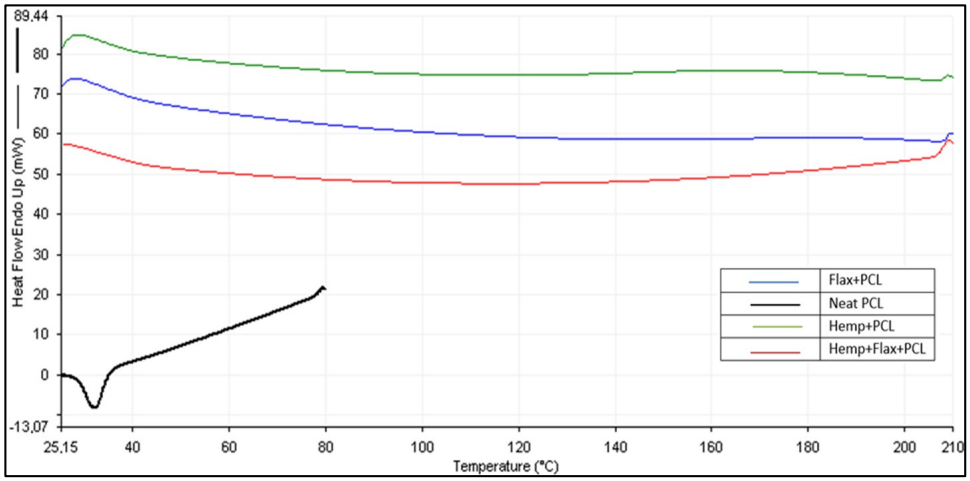


Figure 10. DSC curves representing Tc of different samples.

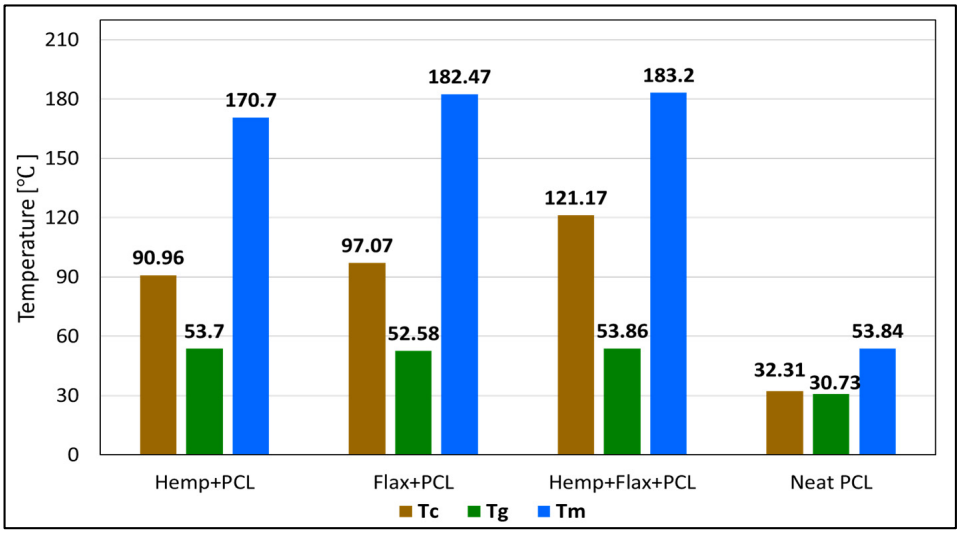


Figure 11. Comparison of DSC results of different samples.

4. Discussion

Hemp and flax fibers were used as reinforcements in this research work to develop hybrid bio-composites, using braiding and compression molding processing technologies with better mechanical properties. The tensile modulus increased by almost 127.12%, and tensile strength by 57.4%, whereas impact strength was increased by 64.14% with the addition of alkali-treated braided fiber yarns. The yield strain of neat PCL showed a little variation with other samples, because PCL exhibited ductile nature as it reached the breaking point. The usage of diamond braid (1/1) helped to obtain proper braid structure by reducing gaps between fibers and thus improving braid strength. The highest impact strength was reported by flax+PCL; this might be due to the larger diameter of flax fibers, which helped in retaining impact energy. Neat PCL observed very less energy due to its semi-crystalline nature. The amount of energy expended during failure is linked to the impact strength. It is likely that the presence of fibers produces areas of concentrated stress, which makes it easier to start a fracture. As long as there was no breakage of the fiber, more energy was used during a fiber pullout in the case of yarn composites, in which the reinforcing fibers are in the form of yarns. The impact strength dramatically increased when longer fibers were added to the PCL matrix because long fiber pull-outs happened often.

Alkali-treated fibers have a substantially lower energy loss through fiber pull-out, and debonding happens after fiber breakage rather than the interfacial debonding often

linked to high energy absorption [20]. Alkali treatment cause fibers to swell, which causes lignin to break down because the hydroxide ions target the carbon ester bonds between lignin, cellulose, and hemicellulose. By breaking the lignin and polymer linkages, alkali treatment eliminates lignin and certain hemicelluloses. The cellulose fibrils are attacked and the matrix is destroyed upon treatment with greater concentrations of NaOH, which weakens the fiber. It is more challenging to estimate how the tensile modulus will change after treatment. In fact, the loss of lignin and hemicellulose reduces the stiffness of the fiber, although improvements in crystallinity and orientation may add up for this loss [21]. From Tables 2 and 3, it can be noticed that the fiber aspect ratio plays a significant role in determining mechanical properties. Moreover, fibers with the lowest AR showed better mechanical properties when compared to higher ones. Choi and Lee reported a small improvement in tensile strength and a reduction in Young's modulus for fibers treated at 5 percent NaOH for 1 h. In contrast, Goda et al. found an improvement in Young's modulus and tensile strength only for fibers with the applied load during mercerization. The present findings thus compare favorably with those in the literature, despite the unavoidable discrepancies [22,23]. A slight improvement in hardness for fiber reinforced composites is being observed. Nevertheless, adding unidirectional fibers did not much affect the hardness values.

Concerning the calorimetric analysis, samples with cellulosic fiber reported a significant increase in thermal properties. The crystallization temperature increased by 275.02%, melting temperature by 240.26%, and glass transition temperature by 75.26%. This might be a result of the removal of wax and pectin from the fibers after alkali treatment, which increased the number of nucleating sites (i.e., a crystalline component of cellulose) in the fibers [24]. Neat PCL showed lower values in contrast to all; this might be due to its semi-crystalline behavior. The obtained values of neat PCL for the DSC test are in accordance with Cocca M et al. [25].

Further, to improve the mechanical properties of bio-composites, the number of braided fiber yarns can be increased inside the samples, which helps to increase strength. Future research on flax and hemp hybrid bio-composites should concentrate on evaluating the materials' impact on the environment, their durability, soil degradation, and their ability to withstand moisture. Surface modification techniques using various solutions should be studied.

5. Conclusions

The outcomes revealed that the addition of braided fibers significantly influenced the mechanical and thermal properties of neat PCL. The tensile properties of the samples were slightly affected due to the high ductility of PCL. As the braiding angle increases, the tensile modulus and tensile strength of the braided composites decrease in the diamond braid (1/1). Hybridization of fibers helped to achieve better mechanical and thermal properties. When compared to hemp fibers, flax fibers have a different reinforcing efficiency that is related to the performance of a single fiber and is responsible for the greatest improvements. The strength of the fiber-matrix adhesion and the fiber aspect ratio (length/diameter), which regulate the effectiveness of load transfer and the extension of the fiber-matrix interface, respectively, greatly influence the mechanical properties of composites in addition to the thermal properties. Hence, braided yarns assisted in improving matrix impregnation and strength of fibers.

There is notable growth in thermal properties upon the integration of fibers. It can be observed that the alkali treatment of fibers helped to improve both mechanical and thermal properties. The addition of an isothermal process helped to improve the glass transition temperature. However, the glass transition temperatures of cellulosic composites remained almost constant. Regardless of the type or weight of the fibers, it was encountered that the crystallization temperature increased when compared to neat PCL. These findings indicate that the PCL chains may find it difficult to reorganize themselves in the presence of fibers and that there may be a weak nucleating influence on the crystal development

of PCL. The crystallinity of PCL increased as a result of hemp and flax fibers influencing the neat matrix's crystallization behavior, having a considerable stimulating impact on the hybrid composites.

Finally, as an illustration of the broader group of bio-based composites, flax and hemp fiber composites provide distinctive combinations of these technical and non-technical concerns, which appear to interest manufacturers. Flax-based composites are utilized to construct musical instruments with acoustic performance that rivals that of traditional wooden instruments, while improving their stability under fluctuating humidity and temperature. It is also used to increase control and comfort in sporting products.

One perceptible component of the sociological and other non-technical properties of flax and hemp fiber composites is their reduced environmental effect. Automobile manufacturers can utilize these materials that can absorb sound, while also being light enough to improve fuel efficiency. Using such hybrid bio-composites in automotive parts not only assists in reducing the component's mass, but also cuts the amount of energy required for manufacturing by 80%.

Author Contributions: A.K.T. contributed with the original manuscript draft writing, data synthesis, and data gathering. J.S. aided with the report's review and research progress. Approach to methodology taken by Y.P.S. and A.K.T. Reviewing the report was aided by the supervision of Y.P.S. All authors have read and agreed to the published version of the manuscript.

Funding: The APC was sponsored by Hochschule Kaiserslautern, whereas no external funding was provided for this research.

Data Availability Statement: Not applicable.

Acknowledgments: The Institute for Plastics Engineering West Pfalz (IKW) is acknowledged by the authors for its financial assistance. It is a research and testing facility run by the Department of Applied Logistics and Polymer Sciences at Hochschule Kaiserslautern, Pirmasens, Germany.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Dhakal, H.N.; Zhang, Z.Y.; Guthrie, R.; Bennett, N. Development of Flax/Carbon Fibre Hybrid Composites for Enhanced Properties. *Carbohydr. Polym.* **2013**, *96*, 1–8. [CrossRef] [PubMed]
2. Pegoretti, A.; Fabbri, E.; Migliaresi, C.; Pilati, F. Intraply and Intraply Hybrid Composites Based on E-Glass and Poly(Vinyl Alcohol) Woven Fabrics: Tensile and Impact Properties. *Polym. Int.* **2004**, *53*, 1290–1297. [CrossRef]
3. Abdelkader, E.M.; Nassar, K.; Melchor, J.; Rus, G. Braiding Thermoplastic and Glass Fibers in Composite Dental Post Improves Their Mechanical Compatibility, In Vitro Experiment. *Materials* **2021**, *14*, 2294. [CrossRef] [PubMed]
4. Dhar, P.; Kumar, A.; Katiyar, V. Magnetic Cellulose Nanocrystal Based Anisotropic Polylactic Acid Nanocomposite Films: Influence on Electrical, Magnetic, Thermal, and Mechanical Properties. *ACS Appl. Mater. Interfaces* **2016**, *8*, 18393–18409. [CrossRef]
5. Pil, L.; Bensadoun, F.; Pariset, J.; Verpoest, I. Why Are Designers Fascinated by Flax and Hemp Fibre Composites? *Compos. Part A Appl. Sci. Manuf.* **2016**, *83*, 193–205. [CrossRef]
6. Dhakal, H.N.; Ismail, S.O.; Zhang, Z.; Barber, A.; Welsh, E.; Maigret, J.-E.; Beaugrand, J. Development of Sustainable Biodegradable Lignocellulosic Hemp Fiber/Polycaprolactone Biocomposites for Light Weight Applications. *Compos. Part A Appl. Sci. Manuf.* **2018**, *113*, 350–358. [CrossRef]
7. Melenka, G.W.; Hunt, A.J.; van Ravenhorst, J.H.; Akkerman, R.; Pastore, C.M.; Ko, F.K.; Munro, M.; Carey, J.P. Manufacturing Processes for Braided Composite Materials. In *Handbook of Advances in Braided Composite Materials*; Elsevier: Amsterdam, The Netherlands, 2017; pp. 47–153.
8. Kobayashi, S.; Takada, K. Processing of Unidirectional Hemp Fiber Reinforced Composites with Micro-Braiding Technique. *Compos. Part A Appl. Sci. Manuf.* **2013**, *46*, 173–179. [CrossRef]
9. Chai, Y.; Wang, Y.; Yousaf, Z.; Storm, M.; Vo, N.T.; Wanelik, K.; Burnett, T.L.; Potluri, P.; Withers, P.J. Following the Effect of Braid Architecture on Performance and Damage of Carbon Fibre/Epoxy Composite Tubes during Torsional Straining. *Compos. Sci. Technol.* **2020**, *200*, 108451. [CrossRef]
10. Malinowski, R.; Raszkowska-Kaczor, A.; Moraczewski, K.; Głuszewski, W.; Krasinskyi, V.; Wedderburn, L. The Structure and Mechanical Properties of Hemp Fibers-Reinforced Poly(ε-Caprolactone) Composites Modified by Electron Beam Irradiation. *Appl. Sci.* **2021**, *11*, 5317. [CrossRef]
11. Durante, M.; Leone, C.; Ussorio, M.; Crivelli Visconti, I. Solution Impregnation of Natural Fibres/ABS Matrix Composites. In Proceedings of the ECCM-11, Rhodes, Greece, 31 May–3 June 2004; Volume 31.

12. Baghaei, B.; Skrifvars, M.; Salehi, M.; Bashir, T.; Rissanen, M.; Nousiainen, P. Novel Aligned Hemp Fibre Reinforcement for Structural Biocomposites: Porosity, Water Absorption, Mechanical Performances and Viscoelastic Behaviour. *Compos. Part A Appl. Sci. Manuf.* **2014**, *61*, 1–12. [CrossRef]
13. Venkata Reddy, G.; Venkata Naidu, S.; Shobha Rani, T. Kapok/Glass Polyester Hybrid Composites: Tensile and Hardness Properties. *J. Reinf. Plast. Compos.* **2008**, *27*, 1775–1787. [CrossRef]
14. Sarasini, F.; Tirillò, J.; Puglia, D.; Dominici, F.; Santulli, C.; Boimau, K.; Valente, T.; Torre, L. Biodegradable Polycaprolactone-Based Composites Reinforced with Ramie and Borassus Fibres. *Compos. Struct.* **2017**, *167*, 20–29. [CrossRef]
15. Madsen, B.; Hoffmeyer, P.; Lilholt, H. Hemp Yarn Reinforced Composites—II. Tensile Properties. *Compos. Part A Appl. Sci. Manuf.* **2007**, *38*, 2204–2215. [CrossRef]
16. Prashanth, S.; Subbaya, K.M.; Nithin, K.; Sachhidananda, S. Fiber Reinforced Composites—A Review. *J. Mater. Sci. Eng.* **2017**, *6*, 2–6.
17. Zhai, W.; Wang, P.; Legrand, X.; Soulat, D.; Ferreira, M. Effects of Micro-Braiding and Co-Wrapping Techniques on Characteristics of Flax/Polypropylene-Based Hybrid Yarn: A Comparative Study. *Polymers* **2020**, *12*, 2559. [CrossRef] [PubMed]
18. Sakaguchi, M.; Nakai, A.; Hamada, H.; Takeda, N. The Mechanical Properties of Unidirectional Thermoplastic Composites Manufactured by a Micro-Braiding Technique. *Compos. Sci. Technol.* **2000**, *60*, 717–722. [CrossRef]
19. Dhakal, H.N.; Ismail, S.O.; Beaugrand, J.; Zhang, Z.; Zekonyte, J. Characterization of Nano-Mechanical, Surface and Thermal Properties of Hemp Fiber-Reinforced Polycaprolactone (HF/PCL) Biocomposites. *Appl. Sci.* **2020**, *10*, 2636. [CrossRef]
20. Hill, C.A.S.; Abdul Khalil, H.P.S. Effect of fiber treatments on mechanical properties of coir or oil palm fiber reinforced polyester composites. *J. Appl. Polym. Sci.* **2000**, *78*, 1685–1697. [CrossRef]
21. Elenga, R.G.; Djemia, P.; Tingaud, D.; Chauveau, T.; Maniongui, J.G.; Dirras, G. Effects of Alkali Treatment on the Microstructure, Composition, and Properties of the Raffia Textilis Fiber. *Bioresources* **2013**, *8*, 2934–2949. [CrossRef]
22. Choi, H.Y.; Lee, J.S. Effects of Surface Treatment of Ramie Fibers in a Ramie/Poly(Lactic Acid) Composite. *Fibers Polym.* **2012**, *13*, 217–223. [CrossRef]
23. Goda, K.; Sreekala, M.S.; Gomes, A.; Kaji, T.; Ohgi, J. Improvement of Plant Based Natural Fibers for Toughening Green Composites—Effect of Load Application during Mercerization of Ramie Fibers. *Compos. Part A Appl. Sci. Manuf.* **2006**, *37*, 2213–2220. [CrossRef]
24. Sawpan, M.A.; Pickering, K.L.; Fernyhough, A. Improvement of mechanical performance of industrial hemp fibre reinforced polylactide biocomposites. *Compos A* **2011**, *42*, 310–319. [CrossRef]
25. Cocca, M.; Avolio, R.; Gentile, G.; di Pace, E.; Errico, M.E.; Avella, M. Amorphized Cellulose as Filler in Biocomposites Based on Poly(ε-Caprolactone). *Carbohydr. Polym.* **2015**, *118*, 170–182. [CrossRef] [PubMed]