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Effect Analysis of Extraction Processes of Bamboo Fiber

Dr. Balkeshwar Singh[1], Mr. Yalew Dessalegn[2]

[1]Professor, Department of Mechanical Design & Manufacturing Engineering, Adama Science & Technology University, Adama City, Ethiopia.

[2]Research Scholar, Department of Mechanical Design & Manufacturing Engineering, Adama Science & Technology University, Adama City, Ethiopia

balkeshwar71@rediffmail.com[1], yalewdesu@yahoo.com[2]

Abstract

This paper review investigated the impact on morphology and mechanical characterization of bamboo depended on the extraction process. The impact of the extraction process on the performance of fibers was reviewed by using various figures and Tables. However, the extraction of plant fibers was difficult as well as complex by nature compared to synthetic fibers. During extraction, the extracted fibers should be produced with long fibers, acceptable quality, and a minimum of damage. Currently, researchers have been developing on the mechanism of fiber separation process which improved to fiber performance like mechanical, and morphological, still, it should be required improvement and modification. Although, most researchers published on fiber extraction process which produced as well as improved the quality of fibers, it had brought defects on the fiber qualities and properties. In this paper, various extraction methods were reviewed regarding process parameters, process input, and the output of extraction methods. Properties of bamboo fibers are discussed in detail based on different extraction methods. There are various methods of extraction of fibers like using compressive milling, roll milling, fiber splitters, steam explosion, chemicals, and a combination of chemicals and pressure.

Keywords: Bamboo fiber, Extraction processes, Mechanical properties, Morphology Properties.

Introduction

Bamboo is often called "natural glass". It has a favorable combination of low density as well as high mechanical performance giving good specific stiffness as well as strength. In the past, several studies had been investigated to characterize single technical fiber [1]. Whilst some reports showed high strength values in the young culm compared to mature ones, most researchers described that the strength increase in the age of six and eight years-old, then decline in all strength in the ages of 10 years old [2]. It was commonly accepted that a three-year-old was used for industrial purposes, but an investigation performed by B. Lybeer et al., [3] summarized that younger would be also appropriate for industrial purposes. Eduardo [4], fibers are extracted from an outer one-third of wall thickness was the lowest values of the strength (Figure 1). The best condition for obtaining the highest tensile values can be reached by extracting at 2/3 of wall thickness from an inside of wall thickness, from a culm of 3 years old (769 MPa). The total mean strength was found to be 643 ± 12MPa (100 mm gauge length). Tensile apparent Young's modulus did not present significant differences along with culm height with a mean value of 27 GPa. Nevertheless, this result opposes the study of Lorena Sánchez Vivas [5], who found a significant variation in the strength of bamboo along culm length and also across culm cross-section.

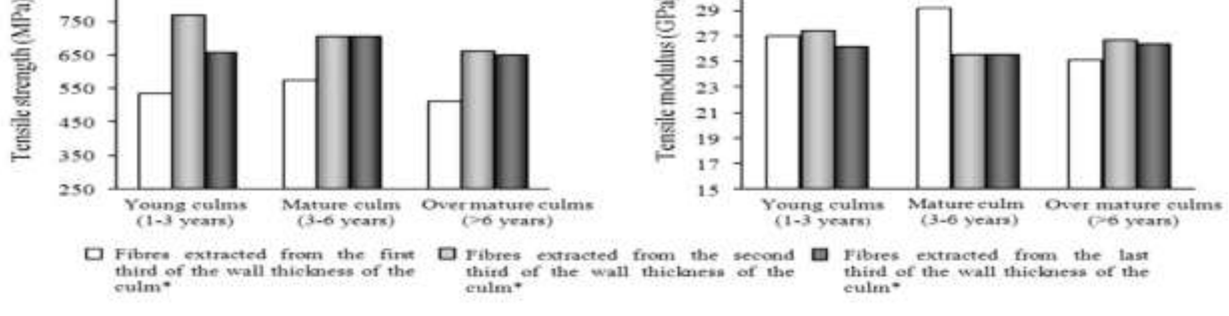

Figure 1. Both (a) tensile strength and (b) tensile modulus (*G. angustifolia*) fibers versus with the age and their position in the wall thickness [4]. * From the outside towards the inner side.

In general, fiber extraction and further fiber manipulation significantly determine a fiber property and performance [6], [7] [8]. Adequate procedure consequence in much better and easier extraction of fibers from the strips, thereby reducing mechanical stress, which minimizes fiber damage. Mechanical overstraining of the strips during the isolation process can create in the formation of defects [7].

Bamboo fibers are biodegradable, light, cheap in cost, low extrication energy, eco-friendly, renewability, recyclability and reduce global warming. However, some limitations of bamboo fibers are susceptible to moisture, low thermal resistance, and difficulty to develop excellent separation methods as well as complex fiber properties [9]. Application area of bamboo fibers is Biofuel Production, Construction material, Food and Feedstock, Musical instruments, Paper industry, Pharmaceutical industry, Textile industry, Cosmetic industry, and Sports industry. Bio-fuel and bio-ethanol are generated from the pulp of bamboo after an additional treatment process. Bamboos were utilized in reinforcement of concrete, making fences, as well as building houses. Moreover, bamboo fibers are substitute to traditional fiber, which have high specific strength, Young`s modulus, hardness, as well as other properties. The bamboo fiber benefited for the production of foodstuff like tea, wine, vinegar, and dry fruits. Moreover, they utilized in the area of food packaging material. Furthermore, they are applied on the application area of textile that have good enough characteristics for spinning and weaving. The plasma treatment used for improve the dye-ability. The time of treatment has positive effect on the roughness and dye-ability, thus leads to improvement in the potential to be utilized for the garment industry.

Bamboo pulp are fabricated from hemicelluloses which can be utilized potentially for the fabrication of paper like printer-paper, copy paper, News-paper, bandage paper, soft tissue, cartons, paper sacks, and filtration-paper [10].The extraction methods have effect on the properties of fibers like absorption, adhesion, mechanical strength and chemical constituents [11].The world are suffer from environmental pollution, global warming, and unstable climate changed due to extension of industrialization Therefore, researcher should develop eco-friendly, low in cost, simple to use, high in yield and quality of extraction methods for bamboo fibers [12].

Since bamboo fibers applied practically for advanced manufacturing process, it would be need to develop good enough extraction machine that extract long and undamaged fibers from bamboo. However, this extraction process might be carried out in a standardized way, and should be able to compete with existing methods for other natural fibers in terms of manufacture volume, price, environmental pollution (e.g. wastewater and chemicals), and uniform consistency in fiber properties. Nowadays, there were several extraction methods used for isolating fibers like mechanical isolation (steam explosion, water retting, rolling mills, compressive mill, and grinding), chemical extraction (acid retting, alkali retting, enzymatic retting), and a combination of both chemicals and others extraction.

Extraction methods of bamboo fiber

Bamboo fibers are used in the application area of the Automotive industry, textile industry, and construction area. However, the extraction of bamboo fibers is complex activities during the separation process from the bamboo culm. Types of extraction methods were determined the quality, and yield of bamboo fibers, moreover, it selected based on the types of application areas. Generally, there are 3 categories of extraction methods of bamboo fiber like mechanical, chemical, as well as the combination of chemicals and other extraction [13].

2.1 Mechanical extraction

Mechanical extraction applied either intermittent or continuous force on the strips using hammer or roller rod respectively, else used high temperature and pressure in the autoclave. However, it required high manpower and good eco-friendly compared to others extraction methods. Types of mechanical extractions are steam explosion, milling, roll milling, compressive milling, and hammering. They used for the production of fiber for fibers polymer composites industries.

2.1.1 Water Retting: Bamboo strips were rinsed in a dish filled with water for 3 days. Finally, these wet strips were flatten, rubbed with a razor , then combed to get long fibers. The drawback of this extraction method was that scrapping of long fibers was damaged and had a strong impact on quality [14].

2.1.2 Crushing Method: Roller crusher used to crush raw bamboo longitudinally into small slabs. Later, putting into the autoclave to get ride of fat and wax from bamboo strips, then, pin rolling used to reduce the size from a strips to coarse fibers, subsequently dried using dryer. A main drawback of this process was yield short fibers, mechanical over-processed fiber and it becomes powdered [9] [14] [15].

2.1.3 Grinding: The procedure of grinding of bamboo culms are cut into strips, immersed into water, split into fine using a razor blade. Wide strips are processed in an extruder to reduce the size of the strips, whereas, long strips were split into fine chips, then they ground in high speed of chopping machine for fabricate fine chips. Different size of sieve utilized to differentiate the size of particles, subsequently XRD and FTIR are used to characterize the crystalline index and chemical composition of the fiber after grinding.

2.1.4 Rolling Mill: In the rolling mill technique (RMT), the diameter of the roller, speed of a rotating roller as well as a gap between two rollers were important parameter during extraction. Fibers from RMT have low tensile compared to the compressive mill technique (CMT). Moreover, RMT produced low average diameter and good fiber arrangement of fibers compared to CMT. The main factors that determine the quality of the fibers using CMT are waiting time, applied load as well as starting bed thickness [16].

First method of rolling mill techniques proposed that the bamboo strips are split into 1 mm thickness, immersed in H_2O for 1 hour, crushed between two roller rod. soaked into water for 30 minutes, separated with a sharp blade into small thickness fibers and dried in sun respectively. The second method of rolling mill techniques suggested that fibers are extracted without any treatment.

The third method of rolling mill techniques proposed that the strips are boiled in the oven, immersed in water to weaken lignin bond, and rolled between two rolling rod respectively. Fibers are produced 30 to 60 cm length [15].The Hygric and thermal insulation property of fibers depended on the extraction technique and process parameter. Therefore, the properties of the fibers and its composites are influenced by the humidity of the region, and moisture content of the fibers during harvesting and extraction [17]. H. Wang et al., [18] prepared bamboo strips sized 1mm x 1mm x 30mm longitudinal that split at two-third of across culm thickness, then soaked a solution of hydrogen peroxide, glacial acetic acid, and distilled for 18 hrs at 60°C. Consequently, crushed fibers rinsed several times in distilled water and dried in the air. They investigated tensile modulus (TE) as well as ultimate tensile strength (UTS) varied at age. TE and UTS were reduced linearly when MC was increased. However, strain elongation at break (EB) resulted minor raise [18].

2.1.5 Steam explosion Extraction

Bamboo was extracted out using high pressure steam in the autoclave, whereas jute, and coir were extracted out using mechanical. According to Biswas, et al. [19] described that tensile strength and Young`s modulus of bamboo fibers are the highest, but strain at failure is the lowest compared to jute and coir fibers.

Jute had smooth surface compared to bamboo and Coir fibers. Bamboo fibers were more crystalline structures compared to jute and Coir. Therefore, bamboo had more fibrils than jute and coir [19].

The steam explosion technique was a very common method to extract natural fibers in general (e.g. flax [20] also hemp [21] . It had been known as an efficient way of separating lignin from woody materials utilized in the paper industry whose diagram was presented in Figure 2. The strips were put into an autoclave at 175 °C, and 0.8 MPa for 60 minutes and suddenly depressurizing to atmospheric pressure. This operation causes micro steam explosions inside parenchyma, facilitating the extraction of fibers a few hundreds of microns in diameter. The process needs to be repeated several times (9-12 cycles) to obtain fine technical fibers [22]

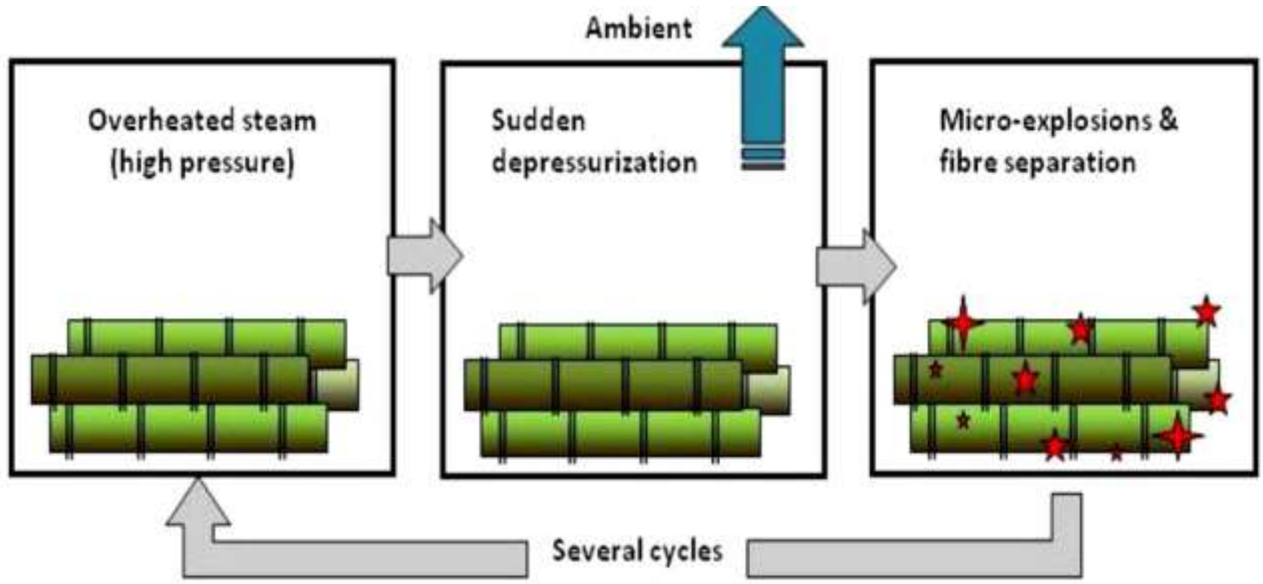

Figure 2. Schematic process for the extraction of fibers by the steam explosion [23].

It had been stated that after using this extraction process, a further mechanical process was necessary to optimize the quality of fibers [23]. The need for this additional step was suggested by Okubo et al. [24], because a technical fibers were not effectively separated and a high amount of impurities and parenchyma remained on it. see Figure 3(a). Therefore, an additional mechanical process consisting of rubbing technical fibers was applied for further separation, see Figure 3(b).

Ashimori et al. [25] used a steam explosion repeating the cycle 10 times. They also complimented the isolation with a mechanical process, where bamboo strips were broken to refine the fibers, to achieve diameters between 125 and 425 µm. A second attempt from the same author to get finer bamboo fibers consisted of freezing the steamed-exploded fibers and so crush them mechanically. Freezing was not a very effective method to reduce fiber diameter, even at cryogenic temperatures.

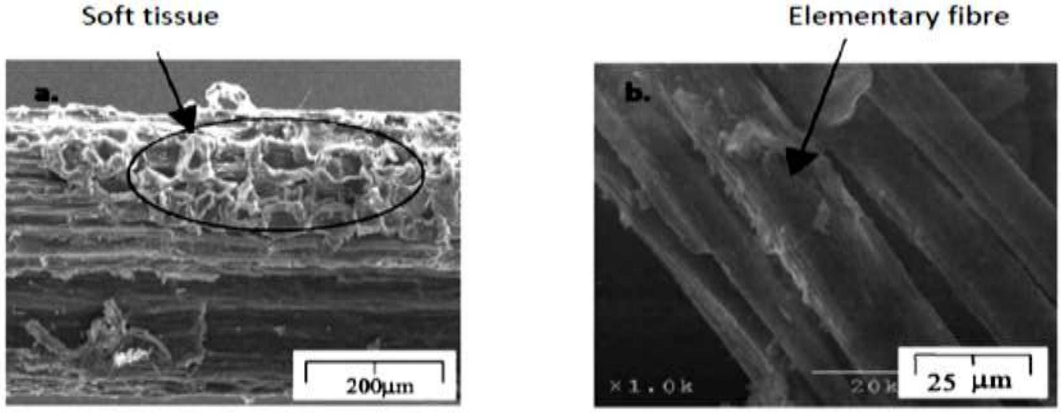

Figure 3. SEM images of (a) bamboo fibers isolated by steam explosion and (b), similar fibers after an extra rubbing process to rinse the fiber. After this process, the fibers appeared as “cotton” fibers obtaining diameters between 10–30 µm [24].

The age of 2–4 years–old, and length of 70–80 cm of bamboo strips are inserted into an autoclave, the fibers rinsed with steam H_2O using detergent for removing ash, and put into an oven with a temperature of 105 °C for 72 hrs respectively [26]**.** As shown in figure 3(a), the SEM image shows that bundles of bamboo fiber are not still isolated, as well as lignin are remained on it. In the figure 3(b), fiber bundles are mechanically rubbed using a cooking mixer for isolate single fibers after steam explosion. Both steam explosion and rubbing process produced a cotton like bamboo fiber that are free from the lignin and produced a very fine fibers [27].

2.2 Chemical extraction

Chemicals which is NaOH+KOH followed to clean using 15 g/L Na_2CO_3. Method A: fibers were immersed into a solutions of 18.5% NaOH, and 18.5% KOH, at moist temperature for 1 hour. Method B: fibers soaked in 0.1 N NaOH at 35°C for 72 hours. Method C: fibers were treated with 0.7% of $NaClO_2$ solution at 90°C for 1 hour with at pH-4, then 2% of $NaHSO_3$ at normal temperature for 15minute. Method D: fibers were cured in 20 g/L of NaOH with 5 g/L $Na_5P_3O_{10}$ and boil for 2 hours. Method E: fibers were cured with a 150 g/L NaOH solution at 80°C for 45minutes. For all of the alkali treatments were used material to liquor 1:40, subsequently clean up at 40°C for 15 minutes [28].

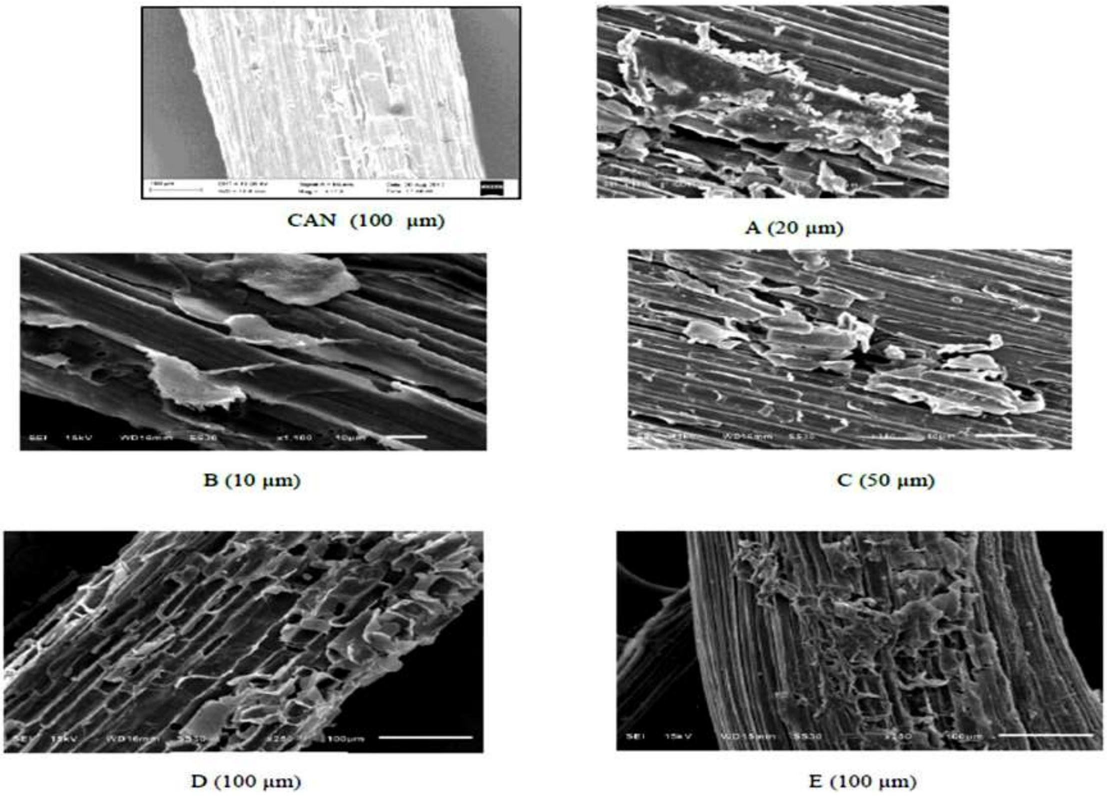

Figure 4 the longitudinal view of a fractured surface of chemical assisted natural retted, and treated bamboo fibers with methods (a) A, (b) B, (c) C, (d) D, and (e) E [28].

As shown in the figure 4 (CAN), chemical assisted natural retting fibers had seen a large amount of gum on it. Methods A, and D have been indicated that a large amount of lignin on the fibers, as well as fiberized. However, Methods B, and E have been seen that free from lignin and smooth surface is formed. Method C has been indicated that fibers are remained in aggregate form. Generally, Method B and E had been seen uniform fiber arrangement compared to method A, C, and D [28]. [29] Strips were immersed in four of chemical solutions for fiber extraction. Four of chemical solutions were arranged: (1) 65% HNO3 and 5% KClO3 added at a ratio of 1:1; (2) 20% $NaClO_3$; (3) 1% H2O2, 4% distilled H_2O, and 5% HAc; and (4) 15% NaOH solutions were heated to 60°C, then strips immersed. Fibers were washed in distilled H_2O to neutrality and air-dried to constant weight after treatment.

Several fiber properties were determined by the four of chemical extraction methods and subjected to ultrasonic treatment. Fibers were isolated HNO_3 + $KClO_3$ required the shortest maceration time and had the lowest contact angles. Fibers were isolated by H_2O_2 + HAc required the longest residence time and had the largest contact angles. Ultrasonic treatment shortened maceration time for all chemical solutions. Tensile strength was decreased in H_2O_2 + HAc, but all solutions were similar after ultrasonic treatment.

The lumen area was changed by NaClO utilization, but the whole-cell wall area was identical for all chemical utilizations. The four methods are produced similar fiber elongations after ultrasonic treatment. These results suggest that ultrasound decreases grinding time and does not have on the whole deleterious effect on contact angle and mechanical behaviors. Bamboo fibers are separated using a splitters, then soaked into a solution of 1%, 2% , and 3% of $Zn(NO_3)_2$ with material to liquor 1: 20 at 40 °C for 116 hours in a container [29][30]. Tianshun, et al. [31] studied that Surface grafting of bamboo fibers (BFs) with 1,2-epoxy-4-vinyl cyclohexane for reinforcing unsaturated polyester. Epoxy vinyl cyclohexane (EVC) did not a problem with the strength weakening in the cell wall.

2.2.1 Alkali extraction

Bamboo an approximately 30x15x1500mm^3 sizes were soaked in alkali solution percentage 0 and 10%wt for 24 hours, then roll milling technique. FTIR analysis suggested that the decreasing of extractives, hemicelluloses, as well as gums. Additionally, no new functional group was observed. Moreover, alkali-treated exhibited better thermal properties and smooth surface compared to the untreated fiber.A performance of fibers was significantly optimized after cured with 10% NaOH for 24 hours. Tensile, as well as modulus, was optimized after alkaline cure [32]. Bamboo strips treated using a solution 0, 1, 3, and 5 wt% NaOH and rinsed in water as well as dried at air for 24 hours. Interfacial shear stress fiber with polyester was optimized when higher bonded length, small contact angle, as well as elevated NaOH percentage. A higher percentage of alkali improved mechanical strength, however, reducing density and strain at break [33].

Untreated fibers have existed a parenchyma and impurities which associated during extraction methods. Moreover, the roughness of the fibers was lower and adhesion too. Fibers pretreated with hot water observed many cracks of cell which improved bonding of fibers with matrix. Whereas, fibers are pretreated with H_2O, and treated with NaOH, thus starch is completely dissolved. Interferential bonding of fiber to matrix improved when the lignin and hemicelluloses contents are reduced due to hot H_2O and NaOH treatment of the fibers [34].

Distance from the outer surface

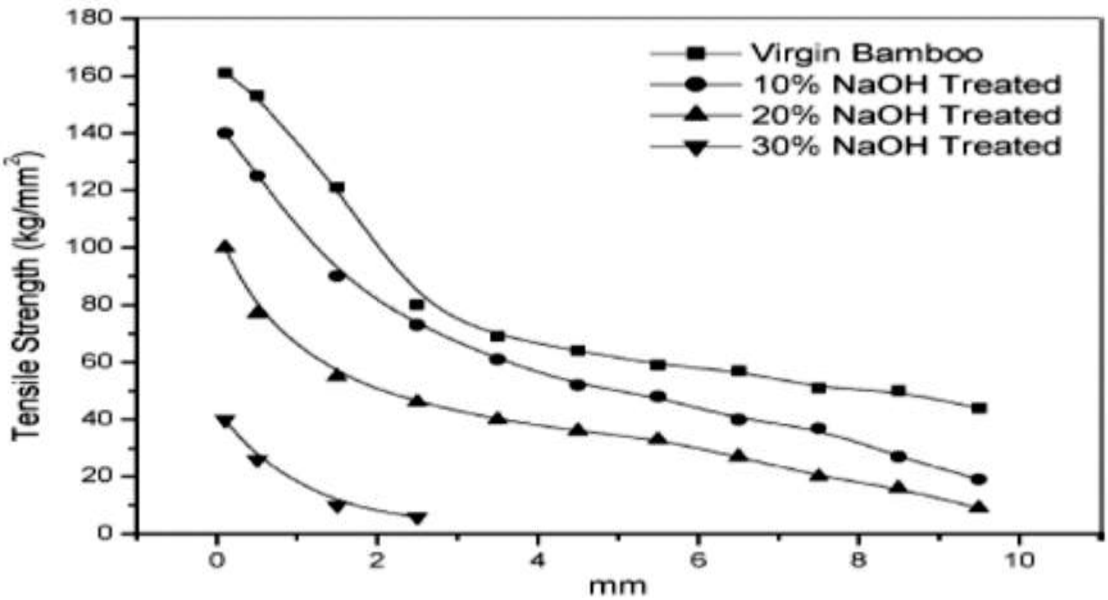

Figure 5. The relationship between tensile strength versus distance from the outer layer [35].

As observed in figure 5, from the highest to lowest tensile of fibers were uncured fibers, 10% NaOH, 20% NaOH as well as 30% NaOH, respectively. 30% NaOH treatment of fibers had lower tensile than 10% NaOH and 20% NaOH. The chemical constituents and mechanical properties of fibers depend upon the percentage of NaOH, temperature and soaking times. When moved from outer to inner bamboo culm, the weight of bamboo was increased whereas the number of lignin contents used as the matrix was decreased, so the tensile of the external bamboo culm was greater than the internal surface [35].

2.2.2 Alkaline retting

Fiber bundles are immersed in 1.5 g/L Na_2CO_3 , and 0.25% Lissapol D at 80 °C for 45 minutes, then they washed with H_2O and dried in open air.

2.2.3 Na2CO3 for polishing

Firstly, the bamboo fibers are treated using sodium carbonate 5g/L, 10 g/L, 15 g/L, 20 g/L, and 30 g/L with fiber to liquor ratio 1:20 at 80°C for 45 minutes**.** The fibers are neutralized using acetic acid, rinsed using hot H_2O at 70°C for 5 minutes, cleaned with cold H_2O, and dried in air respectively [36].

Tensile strength of bamboo/epoxy was greatly affected by percentage of NaOH, soaking as well as drying period. Based on an investigation conducted, suitable curing condition for fiber reinforced with an epoxy matrix was 3 wt.% of NaOH, 9 hours of immersing, and 55 hours of drying (3wt.%-9hours-55hours) [37]. Bamboo strips were soaked into NaOH solution for 3 hours at 5% mass per volume. Then, they were removed from the solution and hammered to get long fiber. Finally, these bamboo fiber bundles were rinsed using HCl to counterbalance the chemicals existing on the fibers. Therefore, they were observed that long fibers are extracted in good quality without any damage. Hence, extracting of long fibers are measured to be the best method [38].

Fibers were soaked in NaOH at various concentrations of 0%, 1%, 3%, and 5% for 20 minutes in dry air. Then, fibers washed in cold water, followed by, in acidified water (20 drops of HCl 0.1Minute 1 L of water) to eliminate excessive NaOH, subsequently washed again, and dried an oven at 60°C for 8 hours. The tensile strength and Young`s modulus of 3% NaOH treated bamboo fibers are improved by 10% and 25%, respectively. Moreover, alkali treatment reduced the mean diameter of the fibers. Furthermore, the interfacial bonding between the fiber to matrix are improved by using alkali treatment due to remove wax, and extractives on the fibers [39].

2.2.4 Acid retting

Bamboo bundles of length 15 cm, and thickness 1.5 mm were soaked 2% HCl, fibers to liquor ratio 1: 25 at dry air for 50 minutes. Lastly, they rinsed in freshwater and dried under shadow [40]. Bamboo culm was split into small pieces (1x5 cm) and soaked in 17.5wt% sodium hydroxide aqueous solution 0.1wt% anthraquinone as additives at 50–70°C for 2 hours, consequently, the temperature was raised to 120°C for 2–3 hours. Softened pieces were ground into individual fiber bundles, then rinsed in boiled water. Cleaned fiber bundles were consequently immersed in 1M hydrochloric acid solution at 60–80 °C for 2 hours, 5wt% potassium hydroxide aqueous solution at 80°C. Followed each process, samples were rinsed in boiled water. The above process is repeated 1–3 times depending on the conditions of separated fibers. Separated fibrils were then bleached with 1.05 wt% sodium hypochlorite solution for 30minute followed by washing in boiled water. Samples were soaked in 1wt% sulfuric acid solution 20 minute, finally rinsed fluent boiled water [41].

2.2.5 Bio retting

Bio-retting process used to reduce the content of hemicelluloses and lignin from the bundles of the fibers. Xylanase and Bacillus sp. are bacteria which produced during bio retting process which removed impurities and gums on the surface of the fibers, and makes weaken bond of the bundles, effective for pretreatment, and ease in extraction of fibers [42].

2.3 Combination of mechanical and chemical extraction methods

Bamboo was cut into a thin bar (300mm x 30mm x 5mm^3) after that fiber extracted using three various methods: steam, alkali as well as chemical extraction. Firstly, 5kg of bamboo strips were inserted into an autoclave, at 175°C, 0.8 MPa, for 55 minutes and depressurized to atmosphere nine times and remove ashes, then washed with H_2O several times, finally dried at the oven. Secondly, strips (5kg) were placed in a container 1.5N NaOH. Then, heat for 5 hours at 70 °C. Thirdly, the chemical process was performed using degumming, this curing also used a NaOH high percentage compared to the alkali solution. Chemical and steam explosion extraction decreased tensile strength and modulus of fiber epoxy composites compared to untreated as well as alkali process. Moreover, steam explosion are damaged the fibers with high temperature as well as chemical extraction are changed chemical structure of fibers with chemicals. Alkali process has low effect on the properties of fibers compared to a steam explosion as well as chemical extraction. Alkali extracted had high contact angle compared to steam explosion and chemical extraction. Additionally, embedded length (Le), as well as height of droplet (h) are the highest value in the alkali extraction of fibers [43].

3.Discussion

Table 1 the influence of extraction methods on the strength of bamboo fibers

Type of Extraction	Parameter of Treatment	σT(MPa)	MOE(GPa)(CV)	EB(%)(CV)	Refe.
Mechanical methods of manual splitting/hammering	Bamboo splitters into strips 2x2x30 mm	830 (0.57)	14.48 (490)	5.85(0.15)	[44]
	bamboo splitters into strips 30x15x1500	252.93	32.1		[32]
	Bamboo splitters into strips 1x0.14x200 mm	179.4	8.7	2.02	[34]
	First roller crusher, then Pin-roller, last boil 90 ºC for 10h	420±170	38.2±16.0	9.8±2.5	[45]
	novel purely mechanical, set length 5–40, thichness 5mm	750	38		[39]
	bamboo strips 2x2x20mm	1320 (320)	30.9 (0.22)	1.84 (0.22)	[29]
	softed in hot H20, extracted mechanically using fine tweezers	1300 (230)	42.0 (0.32)	1.96 (0.30)	
	softed in hot H20, extracted mechanically using fine tweezers	1780 (150)	26.8 (0.06)	2.89 (0.16)	
	softed in hot H20, extracted mechanically using fine tweezers	1520 (300)	18.3 (0.18)	2.80 (0.31)	
	Novel purely mechanical, Gage length(mm) 5–40	775–860	42–46	1.7–1.9	[39]
Steam explosion	heated at 175°C,0.8 MPa., 1h for 9 times.	383	28	2.82	[46]
	180 °C , 0.8 MPa for 90 min. 9 times	615-862	35.45	4.11	[19]
	170 °C , 0.8 MPa for 100 min. 8 times	441	35.9	1.3	[46]
Chemical extraction	CAN 15 g/L Na2CO3	20.07			[28]
	17.5% NaOH and 17.5% KOH at RT for 1h	11.87			
	0.1 N NaOH at 35°C for 72 h	12.6			
	0.7% NaClO2 at 90°C for 1 h treat with 2% NaHSO3 at RT for 15min.	13.5			
	20 g/L NaOH, 5 g/L Na5P3O10 at boil for	10.5			

	2 h				
	150g/L NaOH at 80°C for 45min.	10.2			
	Treated with HNO3 + KClO3	1320 (320)	34.4 (0.20)	2.33 (0.54)	[29]
	Treated with NaClO	1160 (190)	30.5 (0.18)	2.29 (0.22)	
	Treated with H2O2 + Hac	1340 (180)	30.2 (0.22)	2.41 (0.21)	
	Treated NaOH	1450 (360)	19.6 (0.36)	2.49 (0.17)	
	NaOH solution of higher concentration	329	22	2.35	[46]
	(6-25) % NaOH at RT for 2 h	590–680	4.22–11.61	6.06–19.42	[44]
	water retting	275	32	1.18	[47]
	2-8wt.% NaOH for 1-24 h	214–356.8	12.06–27.56	0.76–1.62	
	10wt% NaOH at 24h+RMT	368.33	55.24		[32]
	treated with water at 100 ºC for 1 h	209.4	10.77	1.64	[34]
	treated with 5% NaOH solution at 65 °C for 1 h	234.7	12.22	1.93	
	(1–3)wt% of NaOH	324–395	23.7–26.1	2.54–2.82	[45]
	(1–3)wt% NaOH at RT for 20min.	780–811	40–48.5		[39]
Alkali + mech.	1.5N NaOH, heated for 5 h at 70 °C, pressed machine then steel nail was used	419	30	2.67	[46]
Alkali + mech.	10wt% NaOH at 24h+RMT	368.33	55.24		[32]
CMT+ alkali	Width 1.5-1.75, Thickness 0.65-0.75, 0.1 N NaOH for 72h	644.8			[27]
RMT+alkali	length 8-12cm, Thickness 0.75, 0.1 N NaOH for 72h	370.1			

Note RT: Room Temprature

Extraction methods are categorized into mechanical, chemical, and a combination of chemical and mechanical extraction. As observed in Table 1, parameters of mechanical extraction methods are dependent on methods of fiber separation, a size of the strips, pretreatment of the strips.

From table 1, the top three from the highest to lowest the tensile strength of the fibers, according to the treatment processes are softened bamboo strips into hot water before extraction, novel purely mechanical extraction, and heavy-duty bamboo splitter machine respectively, which the tensile strength (MPa) of these treatment processes are 1300–1780, 775–860 and 830 respectively. The top 3 from the highest to lowest the young`s modulus of bamboo fibers, according to the treatment processes are novel purely mechanical extraction, first the bamboo strips crushed using roll crusher, then, isolate the fibers using pin–roller, last the fibers are boil at 90 ºC for 10 hrs, and heavy-duty bamboo splitters respectively, which the young`s modulus (GPa) of these treatment processes are 42–46, 38 and 32.1 respectively. The top 3 from the highest to lowest the strain of elongation at break bamboo fibers, in regarding to the treatment processes are the strips crushed using roll crusher, heavy-duty bamboo splitters, and pretreatment using hot water, then, extracted using fine tweezers respectively, which the strain of elongation at break (%) of these treatment processes are 9.8, 5.85, and 1.96–2.89 respectively.

As shown from Table 1, the pretreatment using hot water, then, extracted using fine tweezers as well as novel purely mechanical extraction of the fiber are the highest tensile strength, and Young`s modulus from the list of Table 1, respectively. The major factor parameters of steam explosions are the degree of heating temperature, the compressed pressure, waiting time, and the number of cycles to repeated processes to the autoclave.

Biswas, et al., [19] reported that the highest tensile strength (MPa), Young`s modulus (GPa), and strain at break (%) from the list of steam explosion of fibers are 615–862, 35.45, and 4.11 respectively. However, Nguyen, et al. reported [48] is the lowest tensile strength and Young`s Modulus, but it has a high strain of elongation at break compared to Shito, et al. reported [23] from the list of steam explosion extraction methods. The main parameters of factors that affect properties of fibers during chemical extraction methods are type and concentration of chemicals, soaking temperature, soaking time, a ratio of fibers to liquor, and washing time and dried temperature.

As shown in Table 1, the highest tensile strength (MPa), Young`s modulus (GPa), and strain of elongation at break (%) of chemical extraction methods are 1450, 40–48.5, and 6.06–19.42 respectively, which reported by W. Ge, et al [29], Osorio, et al., [39] and Chen, et al.,[44] that treated using 15% NaOH with maceration time 26 hrs., (1–3) wt% NaOH at room temperature for 20min., and (6–25)wt% NaOH at room temperature for 2hrs. respectively. As shown in Table 1, the combination of chemical and mechanical extraction methods depend upon extraction process parameters. The highest tensile strength (MPa), Young`s modulus (GPa), and strain of elongation at break (%) of the combination of both chemical and mechanical extraction methods are 644.8, 419, and 2.6 respectively, which reported by Deshpande, et al., [27], Rawatan, et al., [32], and Kim, et al., [42], that treated using compressive mill technique with 0.1N NaOH at room temperature for 72hrs., roll milling technique with 10wt% NaOH at room temperature for 24hrs., and flattened using a pressed machine then steel nail was used with 1.5N NaOH at 70 °C for 5 hrs., respectively. Generally, from Table 1, from the highest to lowest the tensile strength of bamboo fiber extraction methods are mechanical, chemical, steam explosion, and combination of chemical and mechanical extraction respectively, additionally, in Young`s modulus are mechanical, the combination of chemical and mechanical, chemical, mechanical and steam explosion respectively, moreover, in regarding the strain of elongation at breaks are mechanical, chemical, steam explosion, and combination of chemical and mechanical extraction respectively.

Table 2 The influence of fiber extraction methods on the Physical Properties [27][44][29]

Type of isolation	Type of Treatment	Diameter (µm)	Length (mm)	Area(µm2) (CV)	FA (µm)2	LA (µm)2
CMT		149.15				
RMT		89.87	120			
RMT		96.85	170			
Chemical	Untreated	16.46(4.47)	2.65(0.64)	108.48 (0.26)		

Extraction	(6-25) % NaOH at RT for 2 h	8.02(0.57) – 15.23(1.33)	2.37(0.49) – 3.07(0.65)	88.08 (0.29)- 107.54 (0.26)		
	Treated with (NaClO)				87.2	16.6
	Untreated				119	46.1
	Treated with (H2O2 + Hac)				66	0
	Untreated				72.5	0
	Treated with (NaOH)				83	35.3
	Untreated				89.8	35.7
	Treated with (HNO3 + KClO3)				72.1	18.3
	Untreated				79.9	25.5

Note: FA= single fiber area, LA= lumen area

The physical properties of bamboo fibers depend upon the isolation methods are presented in Table 2. As presented in Table 2, the chemical isolation methods have low fiber diameter (µm), length (mm), and cross-section area (µm2) of fibers compared to mechanical extraction methods [27][44]. The cross-sectional area (µm2) of single fibers and area of the lumen (µm2) is reduced their sizes after the fibers are treated with chemicals [29]

Table 3 the effect of extraction on the chemical compositions [49][45][28][46].

Type of extraction	Treatment process	Cellu. (%)	Hemi cellu.(%)	Lignin (%)	Weight loss(%)	Pectin	Organic extractives	Hot water extractives
Chemical Extraction	The ratio of acetic acid: formic acid = 90:10.	66.98	16.83	3.59				
	Untreated	48.5	25.2	24.4				
Alkaline treated	(1-3)wt% of NaOH	48.8	16.4	22.6				
Steam exploded	heated at 175 °C , 0.8 MPa for 60 min. 9 times	47.4	7.4	23.3				
Chemical extraction	CAN 15 g/L Na2CO3			9	5			
	17.5% NaOH and 17.5% KOH at RT for 1h			8.96	9.42			
	0.1 N NaOH at 35°C for 72 h			8.04	16.87			
	0.7% NaClO2 at 90°C for 1 h treat with 2% NaHSO3 at RT for 15min.			7.13	9			
	20 g/L NaOH, 5 g/L Na5P3O10 at boil for 2			8.27	19			

	h							
	150g/L NaOH at 80°C for 45min.			7.95	20.48			
Chemical extraction	Bamboo pieces	39.4	26.5	23.2		0	4.8	6
	Bamboo fiber bundles (bio retting)	42.3	35.6	19.4		0.2	0	2.6

The effect of extraction on the chemical composition of fibers is presented in Table 3. Percentage of Hemicelluloses and lignin content is reduced after chemical and steam explosion extraction of the fibers, but the percentage co cellulose contents are optimized, whereas steam explosion extraction are reduced a large amount of hemicelluloses compared to chemical extractions [45] [49]. As the concentration of chemicals increase, the percentage of weight loss increase [28]. Bio retting methods reduced the percentage of lignin content, organic extractives, and hot extractives, however, the percentage of cellulose and hemicelluloses content increase, and the new composition of pectin is created [46].

Table 4. the influence of extraction on the crystalline index of the fibers [50]

Type of Extraction	Parameter of Treatment	Crystal. (%)	Amorph. (%)	Cellu.-I (%)	Cellu.-II (%)
Chemical Extraction	Untreated	45.57	54.43	45.57	0
	10 % at NaOH at RT for 1 h	50.1	49.9	35.46	14.64
	15 % at NaOH at RT for 1 h	51.48	48.2	34.03	17.85
	20 % at NaOH at RT for 1 h	47.55	52.55	29.71	17.84
	50 % at NaOH at RT for 1 h	17.82	82.18	1.94	15.88

The crystalline index of fiber depends upon the extraction methods are presented in table 4. 15wt% NaOH at room temperature for 1hrs. of chemical treatment of the fibers have the highest percentage of crystalline from the chemical extraction listed in Table 4 [50]. However, 50 %wt NaOH at room temperature for 1hrs. of chemical treatment of the fibers have the lowest percentage of the crystalline index and cellulose-I [50].

Table 5 the influence of extraction methods on the strength of bamboo fiber polymer composite

Type of Extraction	Treatment	σT(MPa)	E (GPa)	EB,ε(%)	Refe.
Alkaline untreated /treated fibre with EP	Untreated	27.58	0.98		[51]
	(1-4) % NaOH at RT for 12 h	38.25–50.54	1.47–2.56		
Alkaline untreated /treated fiber with EP	Untreated	138.88	4.96	2.7	
	1wt%NaOH,3-9h soak, 24-72h dry	226.85–263.74	3.43–4.50	5.68–7.36	
	2wt%NaOH,3-9h soak, 24-72h dry	253.09–301.52	3.00–3.74	6.67–8.45	
	3wt%NaOH,3-9h soak,24-72h dry	276.98–339.27	3.05–3.70	7.14–8.49	[37]

Alkaline untreated /treated fiber with PE	Untreated	19		0.4–1.8	[52]
	(4-6)wt% NaOH	16.1–21.0		1.5–5.2	
Alkaline untreated /treated fiber with PE	Untreated	518 ± 51	5.96	10.4	[33]
	(1-5)wt% NaOH	187–222	1.31–2.01	15.2–31.6	
Steam exploded/ at 170 °C , 0.8 MPa for 100 min. 8 times	BFcMAPP	35.1	4.69	1.18	[23]
	BFMAPP	30.3	3.66	1.21	
Chemical treatment	Untreated /BPP	31.3	0.9		[16]
	(2-10)wt% silane of amino functional groups/BPP	34.8–35.7	0.8–1.2		
	(2-10)wt% silane of epoxy functional groups /BPP	33.3–34.8	0.7–1.1		
	(2-10)wt% silane of ethyl functional groups/BPP	35.5–36.2	0.7–0.8		

The influence of extraction methods on the strength of bamboo fiber polymer composites is presented in Table 5.

As shown in Table 5, bamboo treated using (1-4)wt% NaOH, at room temperature for 12hrs., 1wt% NaOH, 3-9 hrs. soak, 24-72 hrs. dry, 2wt% NaOH, 3-9 hrs. soak, 24-72 hrs. dry, and 3wt% NaOH, 3-9 hrs. soak, 24-72 hrs. dry reinforced with epoxy composites have high tensile strength, Young`s modulus and strain of elongation at break compared to untreated bamboo fibers epoxy composites, whereas, 3wt% NaOH, 3-9 hrs. soak, 24-72 hrs. dry with epoxy composites have high tensile strength, and strain of elongation at break compared to other chemical treatments of bamboo fibers.

However, untreated bamboo fibers with epoxy composites have high Young`s modulus compared to treated bamboo fibers. Moreover, 1wt% NaOH, 3-9 hrs. soak, 24-72 hrs. dry treated bamboo fibers reinforced with epoxy composites have high Young`s modulus compared to other chemical treatments of fibers [37] [51]. (4-6)wt% NaOH, and (1-5)wt% NaOH treated bamboo fibers with polyester composites have low tensile strength and Young`s modulus compared to untreated bamboo fibers with composites. However, (1-5)wt% NaOH treated bamboo fibers with polyester composites have a high strain of elongation at break compared to (4-6)wt% NaOH treated and untreated bamboo fibers with polyester composites [52] [33].

Bamboo fibers cotton extracted using steam explosion at 170 °C, 0.8MPa for 100min. and 8 times of cycle reinforced with maleic anhydride polypropylene composites have high tensile strength and Young`s modulus compared to bamboo fibers extracted using steam explosion with maleic anhydride polypropylene composites. However, bamboo fibers extracted using steam explosion with maleic anhydride polypropylene composites have a high strain of elongation at break compared to bamboo fibers cotton extracted using steam explosion with maleic anhydride polypropylene composites [23].

As shown in Table 5, (2-10)wt% silane of amino functional groups treated bamboo fibers with polypropylene composites have high tensile strength, and Young`s modulus compared to other chemical treatment of fibers and untreated of fibers with polypropylene composites [16].

Table 6 the influence of extraction on the flexural strength of bamboo fiber polymer composite [16] [39]

Type of Extraction	Treatment	3PBT(Longtudinal)			3PBT(Transverse)		
		σ(MPa)	MOE(GPa)	EB(%)	σ(MPa)	MOE(GPa)	EB(%)
Alkaline untreated /treated with EP	Untreated	310±13	21.1±0.8	2.4	32.8 1.5	2.7 ±0.2	1.3
	(1–3)wt% NaOH,Vf=48% for 20min. At RT	279±10–294± 18	19.6±1.2–23 ±0.6	2.2–2.3	30.8 ±1.3–41.4 2.4	2.8 ±0.1–3.2 0.1	1.1–1.4
Chemical treatment	Untreated /BPP				44.3 ± 1.9	2.1 ± 0.1	
	(2-10)wt% silane of amino unctional groups/BPP				49.2 ± 0.9–52.0 ± 1.7	2.2 ± 0.1–2.3 ± 0.1	
	(2-10)wt% silane of epoxy functional groups /BPP				47.5 ± 0.5–50.6 ± 0.8	2.2 ± 0.1–2.3 ± 0.1	
	(2-10)wt% silane of methyl functional groups/BPP				50.9 ± 0.6–54.7 ± 1.0	2.2 ± 0.1	

The effect of extraction on the flexural strength of bamboo fiber-reinforced composites is presented in Table 6.

As presented in Table 6, the longitudinal flexural strength of treated bamboo fibers using (1-3)wt% of NaOH for 20min. at room temperature with epoxy matrix have low flexural strength, modulus of elasticity and strain of elongation at break compared to untreated fibers with epoxy matrix. However, the transverse strength of treated bamboo fibers has high flexural strength, modulus of elasticity, and strain of elongation at break compared to untreated fibers with epoxy matrix [39].

As presented in Table 6, the transverse flexural strength of treated bamboo fibers using (1-2)wt% silane of amino functional groups, (1-2)wt% silane of epoxy functional groups, (1-2)wt% silane of methyl functional groups reinforced with polypropylene matrix have high flexural performance and Young`s modulus compared to untreated fibers with polypropylene matrix, whereas, (1-2)wt% silane of methyl functional groups reinforced with polypropylene matrix has the highest flexural strength from (1-2)wt% silane of amino functional groups, and (1-2)wt% silane of epoxy functional groups fibers reinforced with polypropylene matrix [16]. As presented (Figure 6a), mechanical extraction stuck lignin and hemicelluloses around lamina, and spread roughly soft tissue on fibers.

As shown (Figure 6b), alkali-processed were uniformly and smooth spread of soft tissue of lignin and hemicelluloses cells were stuck at lamina. Steam-explosion (Figure 6c), most lignin contents were isolated outside a fiber bundle and lignin are reduced on the fiber. Figure 6(c) presented that the creation of pores and fractures inside the fiber that irregularly distribution of lignin as well as holes, then cracks formed on a lamina. Figure (a-c) are SEM observation of single fibers which longitudinally aligned and bonded by lignin and hemicelluloses. Alkaline treated and Untreated fibers had strong bonding between them because of rich lignin. However steam-exploded fibers had weak single-fiber bonding [45]

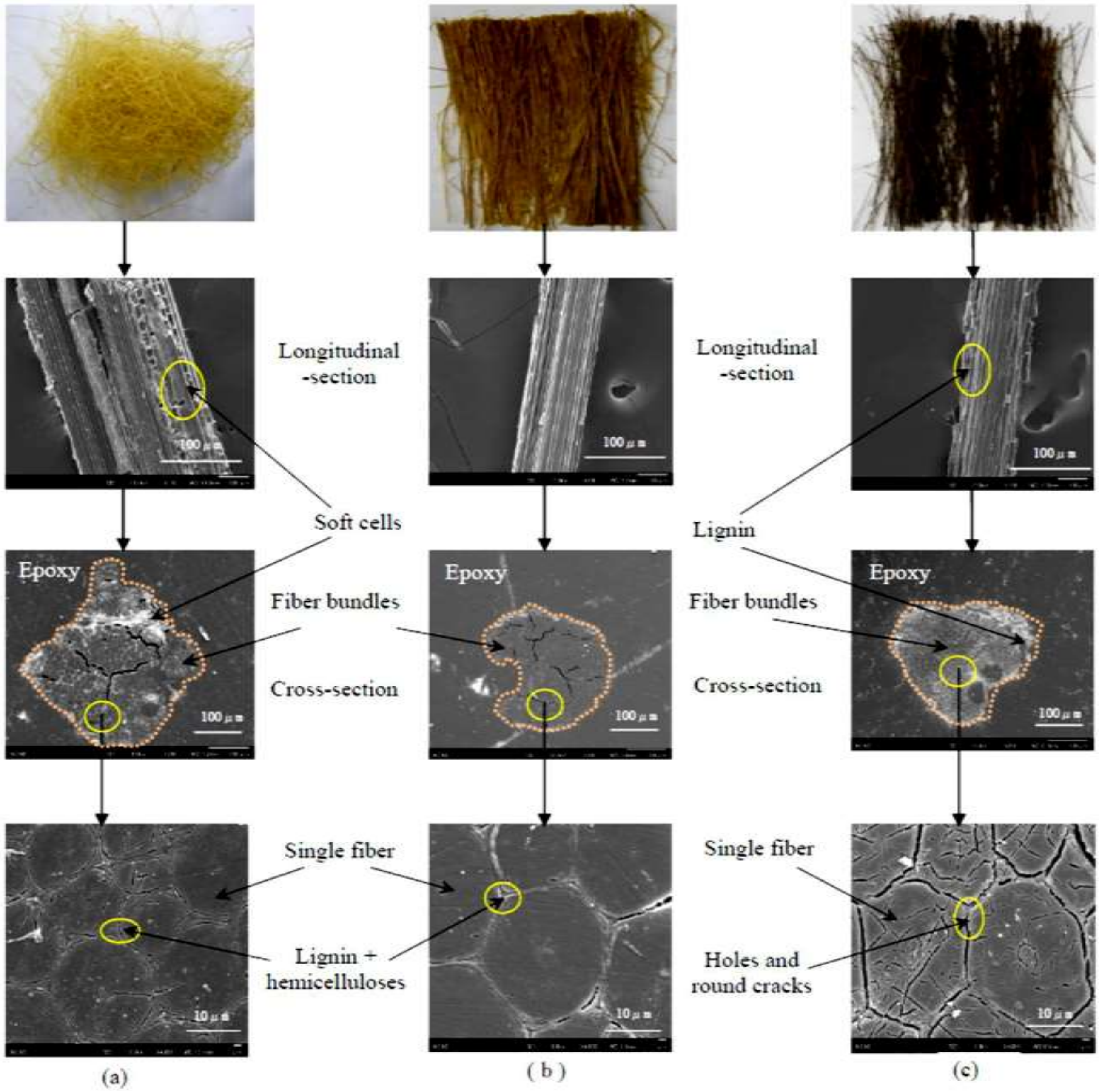

Figure 6. SEM image of longitudinal section of bamboo fiber (a) untreated fiber, (b) Alkaline treated fiber, (c) Steam exploded fiber [45].

In the previous studies, alkali treated fibers have high interfacial strength compared to steam exploded and untreated fibers with unsaturated polyester as well as polypropylene. As presented in figure 6(a), untreated fibers were found more hemicelluloses, lignin, soft cell and impurities that reduced fibers properties like compatibility and interfacial bonding. As indicated SEM image of figure 6(b), alkali treatments have good enough surface, hence good interfacial bonding of fibers and matrix.

As presented in figure 6(c), steam explosion have formed high lignin content and more cracks around the surface of the fibers that are the cause of high temperature and pressure. Moreover, the interfacial bonding of fibers to resin are reduced [45]. Chemical, as well as the steam explosion extraction process, removed more lignin from fibers than mechanical extraction, thus influencing the microstructure, and the performance of the fiber. The Retting and rolling process produced long fibers compared to the chemical, and steam explosion. Grinding and crushing used in produce in the form of particle that used for the evaluation of the rheological and crystallite index. Under a group of chemical extraction, alkali extraction reduced high lignin content; hence fiber-matrix enhanced interfacial adhesion between them. Acid retting removed high lignin content compared to alkali treatment.

Mechanical extraction had high Young`s modulus (GPa) and low fiber diameter (µm) compared to the chemical method. Under a group of combined extraction, Chemical and compression extraction had high tensile strength (MPa) and low density compared to a mechanical method and chemical method [15]. Extraction of bamboo undamaged long technical fibers with a diameter 150µm as well as length equal to internode length was a challenging task. A proprietary, KU Leuven developed mechanical extraction process that produced a considerable fraction about 15% of culm weight of long as well as largely unharmed fibers. The mean modulus of *Guadua Angustifolia* was 43 GPa, and strength attained 800 MPa. The developed pilot machine includes a scouring step to reduce excessive parenchyma tissue.

As indicated in figure 7 comparison of various extraction processes of technical fibers in which mechanical (rolling mill machine) extraction was the lowest tensile (MPa) and mechanical process (in special cases the chemical process is performed) was the highest tensile (MPa) [53].

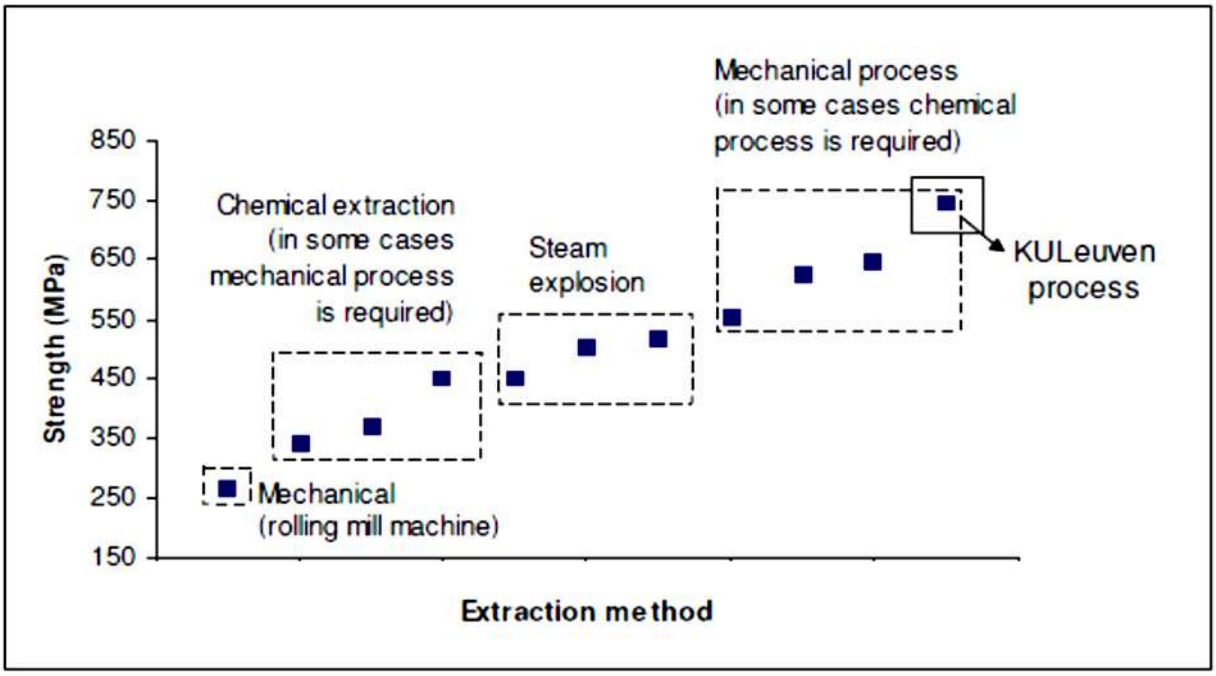

Figure 7. Comparison of various extraction processes for technical bamboo fiber [53].

Conclusion

Bamboo fibers extraction were three in a group, such as mechanical, chemical as well as a combination of chemical and mechanical extraction. Mechanical methods contain a steam explosion, crushing, grinding, roll mill, and retting. Under chemical methods listed chemical as well as alkaline methods. Combined both chemical plus mechanical methods existed chemical + compression and chemical + roll mill. Steam exploded was used to produce the thinnest fiber diameter (µm) and distributed soft tissue on a fiber under observed SEM microscope. It used to loosen to fiber bundles for easy separation of fibers from the matrix which utilized in the manufacturing of pulp products.

Fibers can be produced long and short fiber depending on internode lengths as well as the process of extraction method. Extraction processes had either a positive or a negative effect on the performance of fibers whether mechanical as well as physical or structure of fibers. Chemical methods have changed the chemical constituents of the fibers, thus they affect and damage the structure of fibers. Hence, it reduced the mechanical performance of fibers like tensile and modulus. The parameters of chemical methods are the chemical concentration of the solution, heating temperature, and the waiting period. Mechanical extraction methods were relatively processed within a minimum energy, acceptable fiber quality, and no environmental impact, whereas alkali-treated, and the steam-exploded process had a high length to diameter ratio of fiber and proper control of fiber property. Furthermore, they reduced the high percentage of lignin and hemicelluloses in the fibers.

Generally, mechanical methods have a pessimistic effect on the fiber quality since during mechanical processes, stresses are created which can change the fiber structure and reduce its strength. However, the change in fiber structure did not as huge as chemical processes. Concentration of chemicals and degree of temperature during chemical processes have an opposite effect on the hemicelluloses and lignin contents. Consequently, properties and yield of fibers are reduced. Steam explosion used to making the fiber softer and a lower strength than other types of mechanical and chemical extraction. Therefore, mechanical method has acceptable mechanical properties, best suited eco-friendly, well-situated, and high productivity of fibers compared to chemical method.

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Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

Conflict of interest

The authors declare that they have no conflict of interest

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