End Milling Fabrication of 3 Dimensional Shape Product From Simple Shaped Plate Made of Bamboo Fiber

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Abstract

The manufacture 100% green products of bamboo fiber have been studied in recent years by allowing a green replacement to other composites made from petroleum compounds as the bamboo fibers have a self-adhesive capacity. In this study, a novel fabrication method was proposed and its validation examinations were carried out. The new method consists of creating a simple shaped sample by ball end-milling controlled by a Computer Numerical Controlled 3 dimensional end-milling machine in order to create the finished product. The main advantage of this method is that various shaped products can be fabricated easily from a simple shaped product by using just only one mold, compared to the conventional method where each product requires its own mold for product manufacturing. In the validation tests, the fabrication of a simple shaped thick product was successfully performed. The machining by ball end-milling was used for fabrication of a spoon shaped product from a rectangular shaped product. When analyzing the surface quality, size accuracy and surface roughness of the testing samples, a tendency of the optimal cutting conditions was established. As a result, the spoon shaped bamboo fiber product fabrication was successfully achieved.

KEYWORDS: Bamboo, bamboo fiber, bamboo fiber composite, bamboo fiber green composites, ball end-milling

1. Introduction

The fabrication of bamboo fiber products is being studied in recent years by allowing a green replacement to other composites as the bamboo fibers have a self-adhesive capacity. However, most of the research done so far focus only on fabricating bamboo fiber products by hot press forming, which requires a different die to create a different product.

The present dissertation has the following three main objectives:

1. To study the relationship between density and mass for specimens fabricated by self-adhesive 100% bamboo fibers composite with a simple geometric shape by hot press forming;
2. To know if it is possible to validate the proposed bamboo fiber composites manufacturing process for complex shaped products like a spoon;
3. To study the surface quality parameters when comparing the two manufacturing method's final products fabricated with bamboo fiber composites

2. State of Art

2.1 Bamboo

Bamboo is a very important plant both economically and culturally in many countries of central Asia, such as China, Japan and India [1].

The reason why bamboo is so important in these regions is the fact that bamboo is a plant that not only has very rapid growth and an early maturation, but it also holds good mechanical properties such as high yield strength, high specific strength and stiffness when compared to other materials [2].

However, because of the lack of timber in the bamboo culm and the introduction of new materials such as plastic composites that were easier and cheaper to manufacture than bamboo, bamboo as a product-building material, was heavily replaced by the other timbers and plastic composites.

With the historical drop in the usage of bamboo as a manufacturing material and since bamboo is a grass and therefore has a high rate of reproduction, there was a growth in the forest area of bamboo, forests that now became unused.

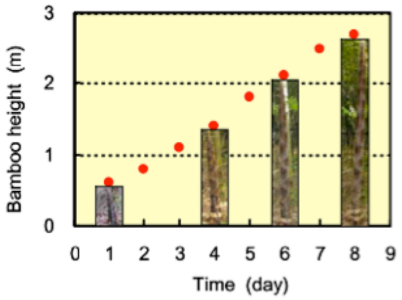


Figure 1 – Bamboo growth in Kyoto[5]

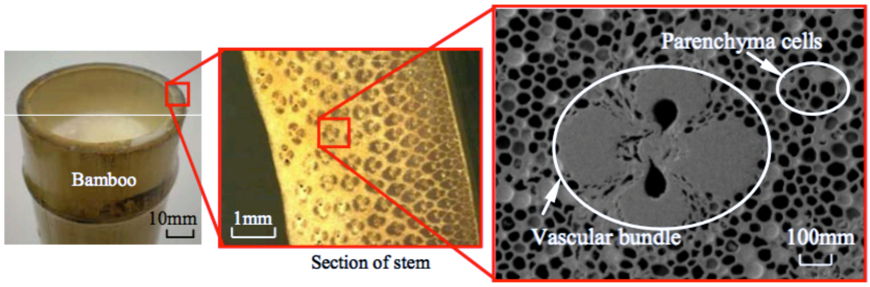


Figure 2 – Cross section of a bamboo pipe and its structural components [16]

The exploration of unused forests to manufacture natural products, if sustainable, is beneficial to the environment [3]. However, these unused bamboo forests are not explored. Not only does bamboo produce oxygen while it grows, but because it is a natural product, its manufacturing could be used to replace other materials that are less sustainable, like plastic and non-degradable composites.

The main motivation of the field of studies where this dissertation is inserted is to take advantage of the unused bamboo forests to manufacture sustainable products.

The growth rate of bamboo is so high (up to 93 cm per day) that it is considered as the plant that has the highest natural growth in the world[4].

Figure 1 ilustrates the growth of a bamboo stem which was tracked in Kyoto, Japan [5].

A bamboo can be considered mature at around 1 to 2 months, when its height is approximately 20 to 30 meters depending on the species and the environment in which the stem grows.

Because of this, recent studies have pointed to the potential of new applications of bamboo in sectors where it was previously not used, such as in manufacturing products with complex shapes [6]. This is mainly due to a bamboo compound that has been receiving more and more attention throughout the years: **bamboo fibers**.

2.2 Bamboo fibers

Bamboo fibers are part of the bamboo culm, in which the matrixes are found, and are characterized by mainly 3 parts:

- vascular bundles - 40% of matrix volume
- parenchyma cells - 50% of the matrix volume
- lignin - 10% of the matrix volume [7]

Vascular bundles and parenchyma cells can be seen in Figure 2 which shows the cross section of a bamboo culm and its components.

Although the fibers have much better mechanical properties than the matrix itself, it is very difficult to separate them and extract them from the parenchyma cells.

There are a number of conventional mechanical and chemical methods of extracting bamboo fibers, but all treat the fibers differently and have different fiber extraction efficiency.

However, none of the bamboo fiber extraction methods is able to accurately control the dimensions of the resulting bamboo fibers. This is a major problem when creating bamboo fiber products because not only the bamboo fibers can be damaged as the bonding properties of the fibers (lignin) may be damaged. Also, none of the conventional extraction methods can control both the fiber diameter and fiber length of the fibers.

Therefore, one study was introduced proposing a new extraction method called machining by end milling [8].

The extraction by machining by end milling method is also aimed for a very high efficiency extraction and a low environmental impact.

The new method consists of using a machining center to extract the fibers of the bamboo. This is illustrated in Figure 3.

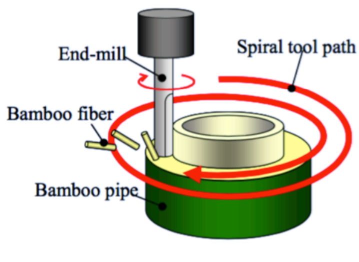
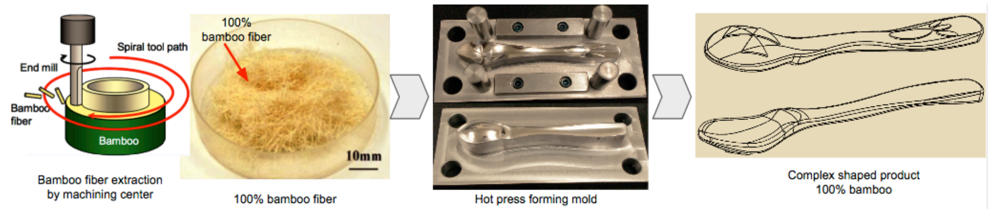


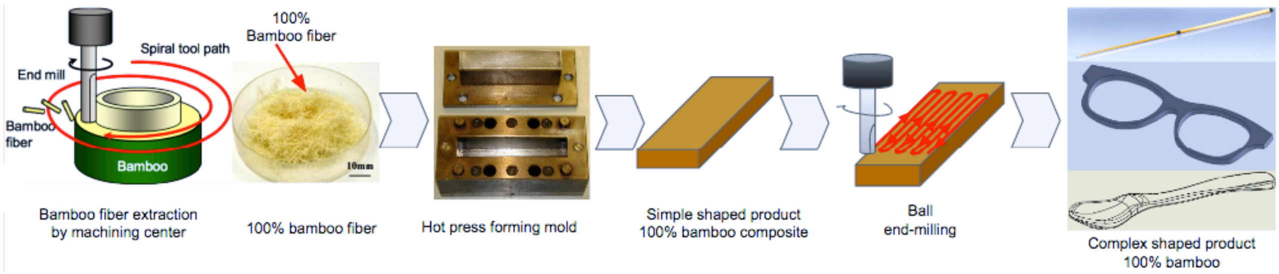
Figure 3 – Fiber extraction by machining center

2.3 Bamboo fiber composites

Because the lignin keeps its properties and because as the bamboo fibers have frequent aspect ratios and so they are high quality fibers, it is now able to create a self-adhesive 100% binder-free bamboo composite.



(a) Conventional



(b) Proposed

Figure 4 – Fabrication methods of bamboo fiber products

The 100% bamboo fiber composites are possible to fabricate by hot press forming, a process that consists in placing the natural bamboo fibers evenly in a mold and then applying pressure and heating [9], creating the self-bonding 100% bamboo fiber composite.

The expected contributions of this 100% bamboo fiber composite to green and sustainable manufacturing are expected as follows [3]:

- high growth-rate of bamboo;
- carbon dioxide (CO_2) absorption while growing;
- low environmental impact during fiber extraction and hot press forming using small-sized machines;
- improvement of energy consumption by in situ measurement and achievement of high-efficient fiber extraction; and
- eco-friendly disposal of bamboo fiber products and high recyclable potential.

The advantages of such bamboo fiber composites are that they represent a natural solution for sustainable composites. They allow the manufacturing of complex geometrical products [6] that could not be made using regular bamboo, have better mechanical properties than other natural fibers, and, because they come from the bamboo plant itself, they have a very high regeneration factor.

3. Proposal

The conventional manufacturing method for bamboo fiber products was introduced [10] and consists in extracting the high quality bamboo fibers from the bamboo and then compress them in a hot press mold to achieve the desired final shaped product. A schematic illustration can be seen in the first two images of the conventional method[6] in Figure 4(a).

In this dissertation, a new manufacturing method as an alternative for the conventional manufacturing method was proposed. The new method consists in creating a simple shaped product such as a parallelepiped by compressing the bamboo fibers and then machining the simple shaped sample by ball end-milling controlled by a CNC 3 Dimensional end-milling machine in order to create the finished product as shown in Figure 4(b).

The main advantage of this method is that various shaped products can be fabricated easily from a simple shaped product by using just only one mold, compared to the conventional method were each product requires its own mold.

Another advantage relies on the fact that the new product can be easily customized and then be used to create such products that require visible trademarks or even prototypes. An advantage like this relies mainly on low volume products, as the machining time may be longer than the time taken to compress the mold into its final shape.

However, the main limitations of such a manufacturing method are that the process requires more than one manufacturing process to be completed and the machining of the simple shape product may damage some of the fiber properties by resizing the length of the original fibers.

4. Experimental Method

3.1 Fabrication of simple shaped thick product

For this study, a machining center end-milling was used to extract the fibers from a bamboo in order to acquire high quality fibers with controllable size[8]. Table 1 shows the cutting conditions for the bamboo fiber extraction.

Table 1 - Bamboo fiber extraction cutting conditions

Spindle speed (rpm)	10000
Feed speed (mm/min)	1000
Radial depth of cut (mm)	0,5
Axial depth of cut (mm)	10
Tool diameter (mm)	6
Tool number of blades	2

The extracted bamboo fibers were then hot pressed into a self-adhesive bamboo composite without any additive, making it a 100% bamboo fiber composite [3]. For the new manufacturing process the die was shaped as the final product and for the proposed manufacturing process, a thick product shaped with a rectangular mold with the dimensions of 125x25mm was fabricated.

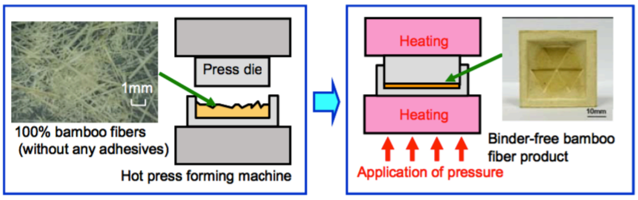


Figure 5 – Hot press forming for the bamboo fiber composites process ilustration

The fabrication of this simple shaped product was studied by analyzing the thickness and density of the plates using the following samples. A study on the density behavior of the thick block product for the different samples is required to understand if the amount of fiber inserted has influence on a homogeneous density in the whole block shaped product.

Table 2 - Bamboo fiber thick plate hot pressing conditions

Amount of fiber (g)	**10, 20, 40, 50, 60**
Width x Length (mm)	25 x 125
Pressure (Mpa)	20
Time under compression (min)	10
Heating Value (ºC)	190

3.2 Machining of thick rectangular shaped product into final shaped spoon product

The machining by ball end-milling was only used in the proposed method. It was done with a 4-axis CNC machine tool with a ball end-mill with a diameter of 4 mm.

To achieve the best product quality conditions, 3 different cutting parameters were studied. The studied parameters were feed speed (mm/min), spindle speed (rpm) and depth of cut (mm) and then the resulting surface quality was evaluated according to the following quality parameters: appearance (or visible quality), surface roughness and size accuracy.

Due to the lack of bamboo fiber test samples, chemical wood was used for pre-processing and machining quality examinations by the above parameters.

After obtaining the best cutting conditions in the chemical wood samples, the bamboo fiber self-adhesive composite resulting from the previous experiment was then machined into the final product shape and the two final bamboo products fabricated by the different manufacturing methods were studied according to their surface quality by the same quality parameters as the chemical wood specimens.

5. Results and Discussion

5.1 Fabrication of thick product

After the bamboo fibers were extracted, they were inserted into a hot press-forming mold with the rectangular shape as seen in figure 5. The result of the different fabricated samples shown in Table 2 can be seen below in the following figure focusing on the thickness of each sample with the amount of fiber inserted.

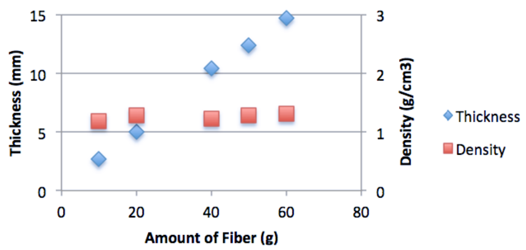


Figure 6 - Influence of amount of fiber on product thickness and density

Figure 6 shows a linear relation between the thickness and the amount of fiber. The density of each sample is calculated by the equation below and can be shown to be constant due to the following relation:

$$\varrho = \frac{m}{V} = \frac{m}{w*l*t} \Leftrightarrow \frac{m}{t} = \varrho * w * l = Constant \Rightarrow \varrho = Constant$$

Is it found that density is almost constant within the samples with different amounts of fiber, even if fiber amount increases. This means that the average density in the whole bamboo fiber product is indeed homogeneous, regarding the amount of

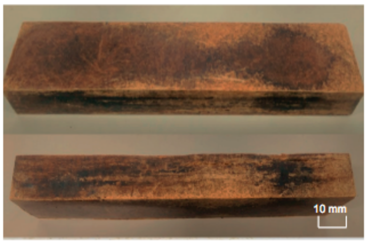
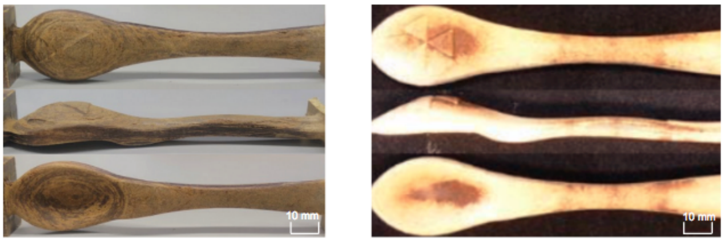


Figure 7 - Hot press formed bamboo fiber thick plate



(a) Proposed (b) Conventional

Figure 8 - Spoon shaped appearance of bamboo fiber product

fiber inserted to create the product.

After analyzing by the dimensions of the CAD design, the 60g specimen was used as it was the only sample with enough thickness to contain the spoon within its height (Figure 7).

5.3 Validation of proposed method

When analyzing the surface quality, size accuracy and surface roughness of the testing samples in chemical wood, a tendency of the optimal cutting conditions was established.

The tendency showed that better surface roughness and surface qualities were observed to lower cut of depths and feed speed.

The influence of the spindle speed in the final shaped spoon product was almost negligible.

The value with the highest influence in the surface quality was the depth of cut. The largest difference of surface quality was observed for the lowest value of depth of cut of 0.1mm and the highest value of depth of cut of 0.5mm in the 1/1 scale chemical wood specimens end-milled.

With the results of the cutting conditions, the bamboo fiber piece was machined with the following cutting conditions:

Table 3 - Bamboo fiber thick plate cutting conditions

	Feed speed (mm/min)	Spindle speed (rpm)	Cut of depth (mm)
Rough	500	10000	0,3
Finish	250	10000	0,1

As can be seen in Figure 8(a), the bamboo shaped product fabrication by ball end-milling was successfully achieved.

5.3 Quality analysis of the resulting bamboo fiber products

The resulted bamboo fiber products fabricated by the different manufacturing methods were analyzed according to the surface roughness, size accuracy and appearance.

The resulted samples can be seen in Figure 8.

An analysis on appearance with the help of a optical microscope was done and 8 points for each of the sides of each bamboo fiber product were analyzed.

Figure 9(a) shows the resulting bamboo fiber product fabricated by the conventional method and Figure 9(b) the specimen by the proposed method.

The surface roughness test results presented varying results on the bamboo fiber product by the conventional method due to the fact that in some areas the bamboo fibers didn't completely bond, as seen in Figure 10, while the bamboo fiber product machined by the proposed method has a much more consistent surface roughness.

Figure 10 - Bamboo fiber product fabricated by the conventional method surface differences

The size accuracy test results can be seen in Table 4.

6. Conclusion

(1) When fabricating the simple shape bamboo fiber product, was observed that the bamboo fiber composite density is constant with the amount of fiber inserted.

(2) The proposed fabrication method was achieved and validated.

(3) The quality difference of the bamboo fiber

Sample	Point A (H) (mm)	Point A (V) (mm)	Point B (H) (mm)	Point B (V) (mm)	Point C (H) (mm)	Point C (V) (mm)
CAD Values	24.2	8.7	7.5	4.8	14.0	6.25
Bamboo Product	24.2	9	7.5	5.0	14.0	6.3
Machined Product	24.4	10.1	7.7	6.6	N/A	N/A

Table 4 – Size accuracy test results on the bamboo fiber final products

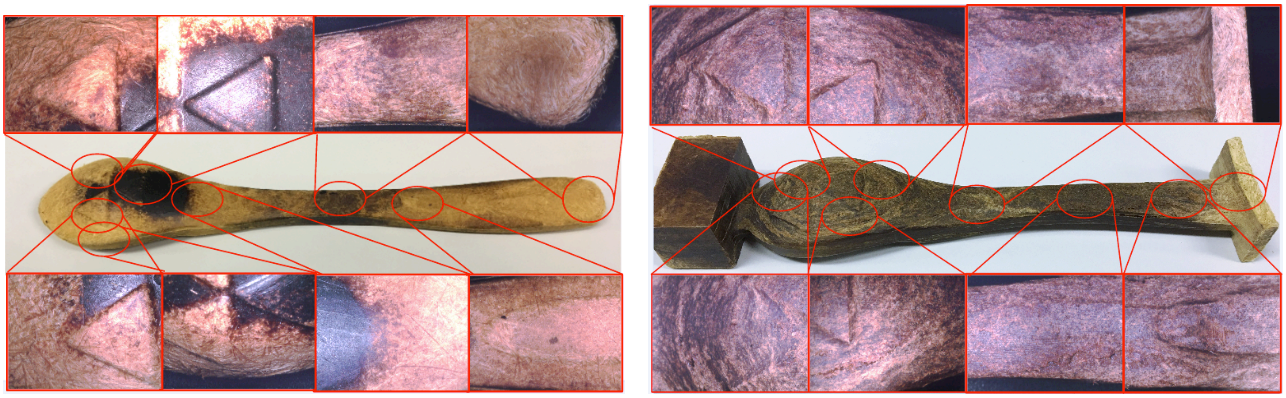


Figure 9 – Bamboo fiber final products appearance areas for the different methods of manufacturing

(a) Conventional (b) Proposed

spoon fabricated by the conventional manufacturing method and the by the proposed method has the following quality aspects:

a. Appearance: The specimen of the proposed manufacturing method was possible to classify as a whole because it presented a very homogeneous surface, where the surface of the conventional method presented 3 different surface qualities, one zone where the fibers completely bonded and the surface is very dark due to heat damage, one area where the fibers didn't bond and the zones in between where the fibers bonded but didn't present heat damage;
b. Surface Roughness: The proposed manufacturing method specimen has a more homogeneous surface all around, but presents mean results; and the conventional method's specimen presents much better results and much worse results, depending on the area in study. This is due to the fact that, in some areas of the spoon the fibers didn't bond;
c. Size Accuracy: The spoon fabricated by the conventional method presented much more accurate results than the proposed method when compared with the theoretical values. This was due to the fact that when machining the proposed method's specimen, a bending moment caused by the end-mill force was visible, which resulted in a thicker value for the vertical points measured in the center of the specimen when compared to the theoretical values of the CAD digital file

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