CHAMU: An effective approach for improving the recycling of tea waste

Pin Gao1*, Yoshito Ogata2

1 Graduate School of Design, Kyushu University, Fukuoka 815-8540, Japan.
2 Department of Design Strategy, Faculty of Design, Kyushu University, Fukuoka 815-8540, Japan.
*Corresponding author’s e-mail: 418480928@qq.com

Abstract. With the development of tea production, treating tea waste has become a problem that cannot be ignored. Here, we reprocessed tea waste to create a new kind of biomass material and named it “CHAMU”. We found that tea waste is a good fiber raw material and can improve the degradation rate of PLA composites in the soil. Based on the above findings, we established a tea waste recycling system. During the processing, it was found that tea stems, tea residue had better plasticity than wood-shaving materials. According to this characteristic, we designed a series of "CHAMU products" to explore "CHAMU" materials in product design.

1. Introduction

Tea, coffee and cocoa are the largest three nonalcoholic drinks in the world [1]. Since tea was distributed over the world, tea demand has increased. The 22nd Intergovernmental Tea Working Group (FAO-IGG/Tea) meeting was held in Naivasha, Kenya, in May 2016. At the meeting, the current tea production and the growth trend of tea production in the next decade were analyzed. According to the analysis, the total world tea production (black, green, instant and other) in 2014 reached 5.13 million tons and will increase at a rate of 3.7% (black tea) and 9.1% (green tea) in the next decade [2]. At the 23rd (FAO-IGG/Tea) meeting in 2018, the meeting confirmed that tea production will continue to grow in the next ten years. The meeting analyzed the growth rate of green tea and black tea and expected world black tea production to grow at an annual rate of 2.2% over the next decade to reach 4.4 million tons in 2027. Global green tea production is expected to grow at a faster annual rate of 7.5% to reach 3.6 million tons in 2027 [3]. The development of tea industry has an important impact on the agricultural development of tea-producing countries. Taking China's tea industry as an example, the output value of China's tea industry exceeds 150 billion yuan (CNY). It has directly affected the livelihood of 80 million tea farmers, and has become one of the core interests of Chinese agriculture [2]. Although the development of tea production and tea economy has many advantages for the tea-producing countries, treating tea waste in the processing has become a problem that cannot be ignored. Tea waste in production can divided into two categories according to production and processing methods. As shown in Figure 1, the first category is the picking up tea stems during processing. Tea stem makes up about 20% of the total weight tea [4]. The other is the tea residue discharged from the tea beverage factory after processing.
Figure 1. Tea Waste (Tea residue and Tea stem)

In the past, producers used in-site incineration for treating tea waste. In recent years, because of the increased awareness of tea waste, the treatment methods have also changed. The treatment method of the tea stem was to collect the tea stems into a bag and use them to absorb the odor to replace the activated carbon. People also can place it in a new car or a newly renovated room to remove odor. Treatment of tea residue was more difficult than tea stems. The watery tea residue carried out from the tea drink factory is prone to rot if not treated in time.

In 2012, the famous Japanese tea drink company “ITONE” produced 51,000 tons of tea residues from tea drinks processing. Of the treatments, 65% was used for compost, 17% was used for heat recovery, and the rest was used as feed or additives [5]. Another Japanese supermarket chain company “TRIAL” also produces tea drinks, and the tea residue each year reaches 1.3 million tons (water-containing tea residue). To this end, the company needs to pay about 12 million yen (JPY) each year to treat tea residue [6].

After realizing the problem of tea waste, the researchers also conducted various studies on it. Tea waste was rich in cellulose, hemicellulose, lignin, theanine, tea protein, tea polyphenols, tea polysaccharides, caffeine, tea pigments, tea saponins, vitamins [7]. In the fields of biomass materials, food processing, agriculture, medicine, and health care, scholars in fields such as Jinxue Jiang et al. used tea residue as a filler to join the MDF to reduce the formaldehyde released. They found that the protein, as one of the main ingredients of tea, was difficult to dissolve in water, which allowed the tea waste residue to maintain its protein. During MDF pressing, the amino group of the protein peptide chain skeleton in the tea residue can react with formaldehyde, lessening the formaldehyde emission of the composite plate [8]. In addition, polyphenols in tea waste can also react with formaldehyde, and has physical adsorption to formaldehyde. Tuan Su pointed out that tea wastes itself are a porous material, which can be effectively to release formaldehyde or promote the reaction to formaldehyde with tea polyphenols when pressed by hot-press machine [4]. In the adsorption studies on formaldehyde, Wan Shunli et al. analyzed the ability of discarded tea residue to purify heavy metals in water. He pointed out the porous characteristics of tea determine the effectiveness of purifying heavy metal ions in water [9]. Bajpai defined tea as an absorbent material with porosity and large specific surface area. It can be seen that tea waste is a good adsorbing material [10].

Although various studies on tea waste have some results, most of them aimed to a single kind of tea waste. They did not give an effective, systematic solution. Tea residue and tea stem were different from each other as waste. If we want to make more effective use of the characteristics of tea waste, we should adopt different processing methods according to its material composition. In addition, current research on tea stems and tea residues mainly concentrated in the chemical industry and agriculture and there has been little research on product development and design related to people’s lives.

Currently, fiber-reinforced plastic (FRP) has been widely used, but most FRPs still cause problems when discarded. For example, when burning waste, the carbon dioxide content in the atmosphere will be increased, and when it is buried in the soil, the waste remains in the soil due to difficulty in degradation [11]. Biomass waste is often mixed as additives with plastics into composite materials in research related to waste degradation. For example, rice shells and bran as additives have been mixed with plastics to improve the degradation of composite materials [12, 13].
The compostability of tea residue has been proven and has been used to produce tea residue organic fertilizer that promotes plant growth [14]. However, there are few studies on the degradability of wastes such as tea stem or composites made from tea waste.

In order to establish a reliable and environmentally friendly tea waste recycling system, tea waste should have good degradation properties in addition to being processable. Therefore, the degradation performance of tea waste still needs to be proved by experiments.

So far, besides tea waste, many wastes have been reused to make artificial materials. Researchers recycled materials such as crop straw, coffee grounds, and coconut shell fibers, and processed them into furniture and other products for people's daily use [15]. But no research related to improving the reusing of tea waste.

2. What is “CHAMU”
To improve the use efficiency of tea waste, we put forward “CHAMU”. The term of "CHAMU" comes from the Chinese Pinyin "cha" and "mu", which means "tea" and "wood". This study’s goal was to reprocess various tea wastes like tea stems and tea residues, and use the wastes to create new material “CHAMU”. As shown in Figure 2, this means “CHAMU” can be instead of wood or other materials.

3. Material and methods
3.1. Tea stem and tea residue hot pressing
As mentioned above, the main components of tea waste were tea residue (water-containing tea) and tea stems. By measuring the tea, the main ingredients of tea were organic acids, tea polyphenols, amino acids, proteins, alkaloids, sugar, pectin and ash [4]. The tea residue discharged from the tea beverage factory was soaked tea leaves, and water-insoluble components in leaves allowed it still keeps such as protein and tea polysaccharide as well as some tea polyphenols, caffeine and amino acids. Tuan Su tested the tea stems by nitric acid-ethanol test. The test results showed the chemical composition of tea stems mainly included cell wall materials such as cellulose, hemicellulose, and lignin, as well as starch, pectin, and other extracts and ash [4]. After measuring the morphology of the tea stems, the fiber morphology of the tea stems are similar to that of the coniferous wood, which shows the tea stems are a good fiber raw material. According to research on the composition of tea waste, the waste can be divided into two types: fiber (tea stem) and non-fiber (tea residue).

In this study, in order to prove the difference in mechanical strength between fiber and non-fiber, we carried out experiments on forming two materials. In the experiment, tea residue and tea stem used as raw materials, and the same hot pressing method was used for processing (Figure 3). The mechanical properties of the formed sheet were tested under the same conditions of density, adhesive ratio, temperature and time.
Our results show that there is a significant difference in the strength of the two materials. The tea residue artificial boards were not sturdy. The modulus of rupture (MOR) of tea residue artificial board was only 1.23 Mpa as determined by the universal testing machine (UTM). The tea residue carbonized during processing because of high temperature, which also reduced the strength of the material. The experiments proved that tea residue is not suitable for producing artificial boards because of its material composition. In contrast to the tea residue material, the tea stems forming a good mechanical strength after hot pressing, and the MOR is 13.2Mpa. Tea stem as a fiber material was suitable for processing artificial board. The formed tea stem artificial board meets the national standard (China) in various mechanical strengths. In addition, artificial boards made from tea stems can effectively control formaldehyde release [6].

Figure 3. Tea stem was formed by hot pressing method

3.2. Study on the relationship of tea stem morphology

Different types of tea stem and even different kinds of tea trees have different fiber shapes. The tea stem has different forms depending on its origin. Taking China’s four major tea-growing regions as an example, tea trees were divided into two types, shrub type, and the arbor type, according to the climate, soil, and precipitation of the producing area. In these two categories, they were subdivided according to the size of the leaves.

To prove the relationship between the types of tea stems and their mechanical strength, we selected Oolong tea stems, green tea stems and black tea stems from the different tea areas. First, we crushed tea stems by using a grinder, and then put it into a vibrating screen. As shown in Figure 4, we placed seven different mesh screens on the vibrating screen to find out the distribution of different types of tea stem pieces on the screen. After 5 minutes of vibrating screening, we measured the fragments of tea stems in each sieve to find out the distribution of the tea stems.

Then, the three kinds of tea stems were made into artificial boards by hot pressing. The processing time, temperature and pressure were all the same. The mechanical strength of the three artificial boards was tested using Universal Testing Machine (UTS).

A strong fiber should be long and thick [4]. In Fig.5, the tea stem fragments having a mesh size of 24-mesh or less were powdery, and fiber morphology was not interwoven to form strength during hot press processing. In fragments above 24-mesh, the tea stems of green tea were similar to the tea stems of black tea. It can be seen in Fig.5, the pieces of the Oolong tea stems were fairly average and a large number of long fragments remained on the 4-mesh screen. Oolong tea stems were thicker than the
stems of black and green tea. This is because the Oolong tea stems used were from tall arbor-type tea trees and the stems of black and green tea came from the dwarf shrub-type tea trees.

It can be seen from the mechanical test that Oolong tea stem from the tall arbor-type tea tree was most suitable for artificial board processing. The tea stem of black and green tea has a certain mechanical strength after molding, but its strength did not reach the Chinese national standard.

Figure 4. Oolong tea stems were placed in vibrating screen machine
3.3. Degradation of tea waste

In the experiment of the biodegradability test of samples, we used the soil burial method. The soil contains various microorganisms that can degrade plant material [16-18].

Three different kinds of wastes were used for experiment: the tea stems powder, tea stem fiber and tea residue powder. Tea waste was mixed as a filler with Polylactic Acid (PLA) particles in three different proportions: Sample 1 (50% tea stem powder 50% PLA), sample 2 (50% tea stem fiber 50% PLA), and sample 3 (10% tea residue powder 90% PLA). We pour the material when the extruder temperature is heated to 165 degrees. After high-temperature extrusion molding, the semi-finished product was obtained. The three kinds of semi-finished product obtained from the experiment were further subjected to pulverization, drying, and injection molding to obtain the final experimental sample (Figure 6). Then the shear strength of the three samples was determined by the UTM.
For the degradation test of PLA and tea waste’s composites, we used the method of outdoor soil burial. Outdoor, garden soil was used as an experimental soil and the three different experimental samples were buried. The test period was 4 months. Every month, we took the experimental sample out, washed, and dried, and weighed sample to measure the weight loss rate. The loss weight was calculated with a simple equation \[^{19}\]. After 4 months, the mechanical strength tests were again performed on the three samples.

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\text{% Wt. Loss} = \frac{W_i - W_f}{W_i} \times 100\%
\]

\(W_i=\) Initial wt. at the beginning
\(W_f=\) Final wt. after every month

After 4 months of soil burial method experimental, all three samples degraded to varying degrees. The loss weight rate of sample 1 is 55.2\%, sample 2 is 44.4\%, and the sample 3 is 18\%. In addition, the specific analysis of the experimental data per month shows that the degradation properties of the material changed with the extension of the experimental time. After 4 months of soil burial experiments, the mechanical strength was again tested on the three samples. The test results showed that the mechanical strength of the three samples had different degrees of decrease, sample 1 declined 86\%, sample 2 declined 81.5\%, and sample 3 declined 40\% \[^{20}\].

It can be seen from experiments that biodegradation is accompanied by a decrease in mechanical strength. Yoshito Otake showed in his study that, it is mentioned that microbial active soil has a greater impact on the degradation of materials \[^{21}\]. Ogawa mixed 20\% of bran with PLA and observed that the mechanical strength for the material dropped drastically in a 30-day soil burial experiment. By measuring the amount of microorganisms in the soil, it is found that these plant wastes have caused the microorganisms in the soil to increase by 100 to 1000 times \[^{12}\]. Therefore, it can be known that the decrease in the mechanical strength of the material is related to the reproduction of microorganisms. This study proves that using tea waste as a filler to make PLA and tea waste composites can improve the degradation in natural environments.

As shown in Figure 7, we established a tea waste recycling system based on this research results and characteristics of tea waste. Through the cooperation of farms, factories, and shopping malls, the “natural power (the microbes in nature)” will make the “CHAMU” products biodegradable, turning them into fertilizer to return to the land to solve the problem of tea waste disposal and improve the value of waste utilization.
3.4. The “CHAMU” Product

The processing properties and degradation properties of tea waste studied above. But the production tea waste was far less than wood waste such as wood particles. If only used as an artificial board, the value of tea waste can't fully realize. During the processing, it was found that tea stems, tea residue had better plasticity than wood shaving materials. According to this characteristic, we designed a series of "CHAMU products" to explore "CHAMU" materials in product design. The hot-pressed "CHAMU" material was processed again by CNC (computer numerically controlled) machine, it gives "CHAMU" various shapes to meet the different needs (Figure 8).

It is true that tea waste is not as productive as wood or other agricultural waste, but tea waste has characteristics that can be distinguished from other materials, the tea aroma and the tea culture.

Tea waste contains a large amount of aromatic compounds, especially tea stems, which are rich in aromatic compounds and are the main source of aroma in tea processing. This unique tea aroma is the greatest feature different from other materials. For example, Figure 9 is the design work based on the concept of “CHAMU”. This is the tea packaging made by tea stems. Tea stems of the packaging and tea in the packaging come from the same kind of tea, which means users can judge the type of tea by just smelling the aroma of the CHAMU tea packaging. After the forming of the tea package, the aroma will be slowly released during a whole year and the concentration of aroma will decrease gradually over time. In this situation, users can also judge the approximate storage time of tea by smelling the aroma concentration of CHAMU tea packaging.

Tea culture, which originated in China, has a history of thousands of years. At present, the research on tea waste has not been considered from the cultural point of view. But the tea waste is also a form of "tea". Based on the “tea waste recycling system”, the visual performance of “CHAMU” will be redesigned so that “CHAMU” will has the cultural image of “tea”. In the past research on cultural imagery, products that effectively express cultural imagery can improve user satisfaction. Therefore, the research on the "connotation characteristics" of tea waste based on the "tea waste recycling system" can expand the design potential of "CHAMU" and to be effectively distinguished from other materials to achieve high value-added reuse of tea waste.
4. Conclusions
In this study, several methods were used to understand tea waste formation and degradability, and the design potential of tea wastes. The research results of various aspects are as follows.
1. Tea waste was processed by the hot-press method. The mechanical properties of tea waste artificial board were tested by a Universal testing machine, which conformed to the national standard of the artificial board (China).
2. The distribution of the tea stem pieces of different tea types was measured, and tea stems of the arbor-type tea trees were more suitable for the processing of artificial board.
3. Over a period of four months, the experiment proved that tea waste as filler could improve the degradation performance of the material.
4. A tea waste recycling system was proposed.
5. We designed a series of "CHAMU products" to explore "CHAMU" materials in product design and discussed the design potential of this material.

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