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Development of Pavement Blocks Made of Bamboo Fiber for Pedestrians as a Community Development Tool

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Abstract - *The purpose of this study is to improve the practicality of paving blocks made of bamboo fiber taken from abandoned bamboo groves. The bamboo block composes of bamboo fiber and cement and water without any chemical additive. In some cases, bamboo powder finer than bamboo chip can be layered on the top of the block to smooth the surface for pedestrians.*
Pavement materials made of bamboo fiber have already been studied, and examples of the practical use can be seen. However, they are not pavement blocks. The bamboo fiber block developed in this study does not basically require the construction technique to pour pavement material and form the surface all over the ground. If some blocks break, anyone just replaces them. New bamboo pavement block is not only much lighter and replaceable but also low price compared to conventional concrete pavement blocks.
Eventually, a circular plaza paved with the 340 bamboo pavement blocks was constructed at the vacant lot of the Ashikaga city's land in November, 2021 as an exposure test.

Key Words: **Bamboo Fiber, Concrete, Pavement Block, Exposure Test**

1.INTRODUCTION

1.1 Aim and background of the study

This paper discusses the background, production method, and features of the bamboo fiber blocks used for pedestrian pavement.

A bamboo fiber block is a paving block made by mixing cement with pulverized bamboo chips and powder (Fig. 1).

Fig -1: Bamboo chip(left) and bamboo powder (right)

The blocks were created in a collaboration between university students and townspeople in the city of Ashikaga and financially supported by the government of Tochigi Prefecture, Japan since 2015.

Tochigi Prefecture, surrounded by mountains, is famous for its bamboo production [1]. There are many vast bamboo groves in Ashikaga City and neighboring Sano City. On the other hand, abandoned bamboo groves have recently become a bigger problem due to the decline of the forestry industry. The problem has been addressed from the viewpoint of the Sustainable Development Goals（SDGs）.

This project was implemented as part of the "Creating a Lively Ashikaga City" plan that generated communication among townspeople on the nightscape by bamboo lanterns made by cutting down from abandoned bamboo groves (Figs. 2 and 3).

The bamboo lantern events raised awareness in the region and achieved certain results. However, the large number of used bamboo cylinders for the lanterns was a major problem. Moreover, the bamboo cylinders decay in about a year and become unusable. Therefore, further action is necessary. Bamboo cylinders can be reused to create bamboo fiber blocks by pulverizing the bamboo cylinders.

This paper discusses the following procedure: firstly, the background of the development of the bamboo fiber block will be described in detail. Next, after describing the manufacturing method of bamboo fiber blocks, their features based on strength experiments are explained. Finally, it explains the result of the bamboo fiber blocks exhibition conducted in November 2021, which was implemented as an exposure experiment.

1.2 Reviews of precedence research for the paving block by the bamboo fiber

There are some previous studies on pavement materials using bamboo fiber. Some of them are similar in material composition to the block in this research. For example, there is research on mixing bamboo fibers with cement to form pavement blocks abroad [2&3]. However, aggregates (gravel, etc.) are mixed in to ensure strength, so

the source of this research is different from pavement material that is only made of bamboo and cement.

Fig -2: Students cutting down bamboo in an abandoned bamboo grove in Sano City (left) and Making bamboo cylinders for bamboo lanterns (right)

Fig -3: Bamboo lantern event at the vacant land in the city (left) and Bamboo lantern making workshop with local children (right)

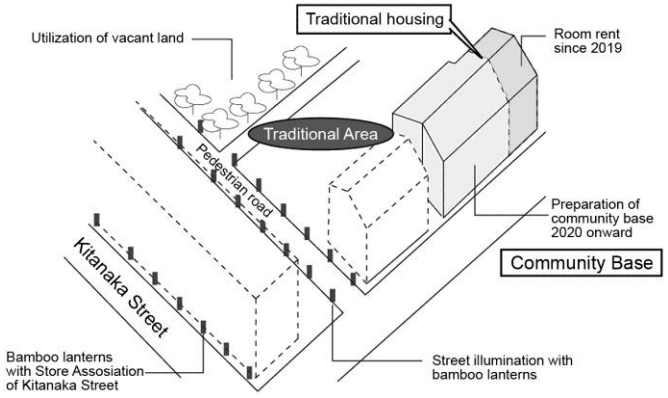

Fig -4: Setting up the base and continuing activities rooted in local communities

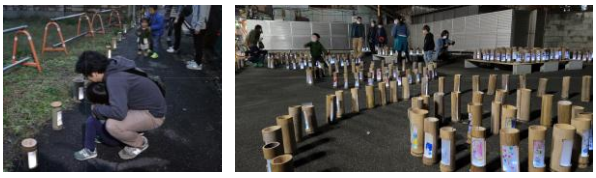

Fig -5: Parents and children gathering in a back alley (left) and long-term exhibition using 500 bamboo lanterns made in collaboration with kindergarten children (right)

In Japan, soil paving materials mixed with bamboo fiber have been developed [4&5], but it is different from the development of paving materials with replaceable blocks in this research. Furthermore, there is also a bamboo block as a building material in domestic patents. Its block uses only bamboo powder, which has a shorter fiber length than bamboo chips, and cement [6]. Compared to creating paving material with chips, it requires more than double the amount of bamboo, so it is not as lightweight.

This study develops a very lightweight and reasonable pavement block for pedestrians using only bamboo chips and cement. As a result, it is expected that it will be used as a community development tool that can be replaced easily by residents if a paving block becomes damaged, and can be used to improve the local environment at any time.

2.DEVELOPMENT BACKGROUND OF BAMBOO FIBER BLOCK

2.1 Summary of the bamboo lantern and its event

Various events have been held using bamboo lanterns since 2015 [7&8]. In addition, instead of holding the bamboo lantern event as a temporary event, the base for a regional collaboration project was set up in the Yukiwa area in Ashikaga City to study and practice a method for supporting activities of local people (Fig. 4).

Bamboo lanterns are bamboo cylinders 25 cm in height with a hole in the side and an LED light inside. They are a device for brightening the nightscape and are lined up on the roadside and in the square to illuminate the ground.

The bamboo lantern events consist of two approaches (Fig. 3). One is to set up bamboo lanterns in town at night and attract people to the lights. The other is to share the fun and create liveliness through making bamboo lanterns with kindergarten children and holding on-site bamboo lantern-making workshops for local children and residents.

For example, university students collaborated with five kindergartens in the city to make approximately 500 bamboo lanterns together in 2020 [9]. University students made bamboo cylinders in an abandoned bamboo grove and opened a window on the side of them. The children drew colorful illustrations on the tracing paper that covered the windows of the bamboo cylinders. These 500 bamboo lanterns were installed over a period of about a month from the base in the Yukiwa area to the dimly lit back alleys of the area. Bamboo lanterns illustrated with shops' names were set in front of 30 shops' eaves in the area. As a result, people had the opportunity to gather in the back alleys and shops in the area, which were not usually crowded (Figs. 5 and 6).

2.2 Problems seen in bamboo lanterns

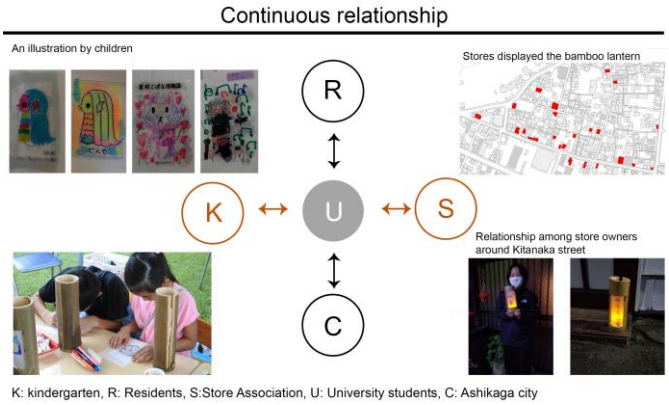

Fig -6: A kindergarten and a store association that collaborated on bamboo lanterns. In addition to this, students from Ashikaga technical high school and elementary school children also collaborated on bamboo fiber blocks.

The following two problems came to light when proceeding with the bamboo lantern events. 1) The bamboo cylinders used for the bamboo lanterns are damaged considerably in one year, and 2) in the case of long-term exhibitions, there are legal rules regarding the use of roads, and the bamboo lanterns must be fixed to the ground. As a solution to these problems, the development of bamboo fiber blocks was started to create a pavement material made by pulverizing bamboo cylinders and mixing them with cement after using them for bamboo lanterns.

3. COMPONENTS AND MANUFACTURING METHOD OF BAMBOO FIBER BLOCKS

3.1 Technical background and prior art of bamboo fiber blocks

Conventional pavement blocks, from the viewpoint of reducing environmental impact and improving walking performance, have already been improved. For example, there are cement blocks made by mixing bamboo fiber with sand and gravel to improve water retention and at the same time give the texture of natural materials.

Improvement of workability, however, is also important for paving blocks that must be used in large quantities. The major problem regarding workability is the weight of paving blocks.

Commonly used pavement blocks are cement blocks, bricks, and stones, which are composed of 70 to 80% sand and gravel, so the blocks themselves are heavy. Therefore, it is not easy to place a large number of blocks in a large area.

On the other hand, there is a prior art that aims to significantly reduce the weight of cement blocks by developing cement blocks that consist entirely of bamboo powder with short fiber lengths, without using sand or gravel [6]. Although this technology was not originally for paving blocks, it has sufficient strength to be adapted for this purpose.

As seen in this prior art, bamboo fibers have an average fiber length of about 10 mm, mostly powder with a range of 1 to 30 mm. Powder is used because it is easy to manufacture concrete moldings through adjustment within this range.

However, if the bamboo fibers are fine, they are densely packed without any gaps, so a very large amount of bamboo powder is required, and the weight increases accordingly. Moreover, simply increasing the length of the bamboo fiber reduces the adhesive surface between the bamboo and cement, weakening the bond and making it difficult to maintain strength.

Therefore, there has been a demand for a lightweight pavement block that can maintain sufficient strength while using long bamboo fibers.

3.2 Composition and method of the production of the bamboo fiber block

The manufactured bamboo fiber block consists of two layers: the upper layer is a coating made of powdered bamboo fibers that have a fiber length of 30 mm or less with cement. The lower layer is made of bamboo chips which have a fiber length of 30 mm or more and 100 mm or less with cement. (Fig. 7).

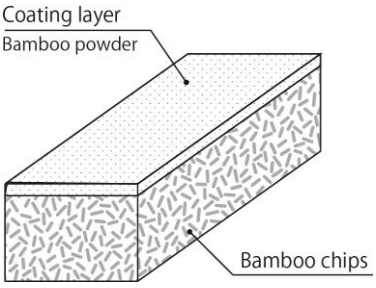

Fig -7: Composition of bamboo fiber block.

The block manufacturing method is as follows (Fig. 8).

Step 1 is the measurement of the material to form the lower layer of the block.

The materials are bamboo chips, water, cement, and organic admixture. It is desirable that the water-cement

ratio is 0.40 and the admixture is added at 0.7% of the weight of the cement. Fine aggregates such as sand, gravel, and resin are not used at all.

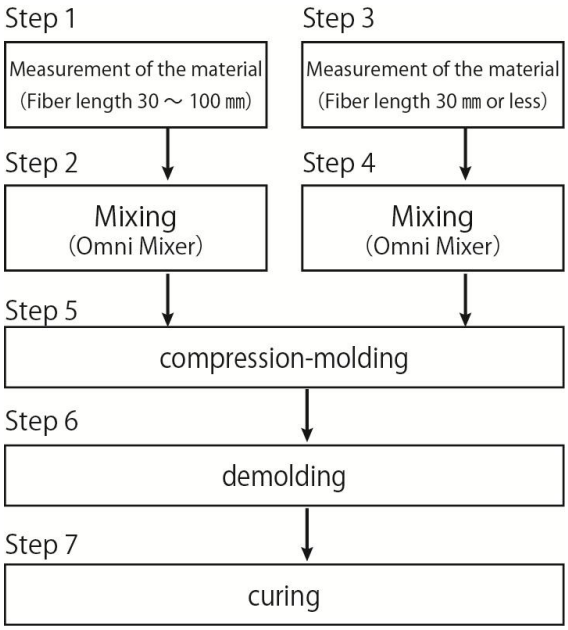

Fig -8: Manufacturing process of bamboo fiber block.

The bamboo chips are Madake bamboo (Phyllostachys bambusoides) or Moso bamboo (Phyllostachys heterocycla f. pubescens) which have been pulverized with a chopper and dried to a moderate degree. There is no need to consider the moisture inside the bamboo through drying and it does not affect the water-cement ratio. However, it does not have to be completely dry.

Regarding the fiber length of bamboo chips, there is an inverse relationship between the fiber length and the weight of the molded block. For example, bamboo chips composed of longer fibers are lighter. If the fibers with a length of 50 mm to 100 mm exceed 75%, the joining surface between the fibers is too small and the necessary strength cannot be achieved. 50-30 mm fiber length size should comprise 20-30% of the total quantity of bamboo chips. As a result, the number of joining surfaces between bamboo fibers increases, the bond strength between fibers become stronger, and the inherent bending strength of bamboo can be exhibited.

In step 2, the bamboo chips measured in step 1, water, cement, and an organic admixture are uniformly mixed with an Omni Mixer, which is advanced mixing with a rotation speed of 100 to 480 RPM. By using an Omni Mixer for mixing, the cement can be thinly and evenly distributed across the surface of the bamboo chips. Even if this is done with a conventional Pan mixer (rotation speed 20-30 RPM), it is quite difficult to evenly cover the surface of the bamboo chips with the cement, because water and cement will gather at the bottom of the mixer.

Step 3 is the measurement of the material used in the upper coating layer. The materials are bamboo powder with a fiber length of 30 mm or less, water, and cement. The water-cement ratio is 0.30. The organic admixture may not be used. The weight of the bamboo powder should be about 50% of the total weight. The bamboo powder uses Madake or Moso bamboo.

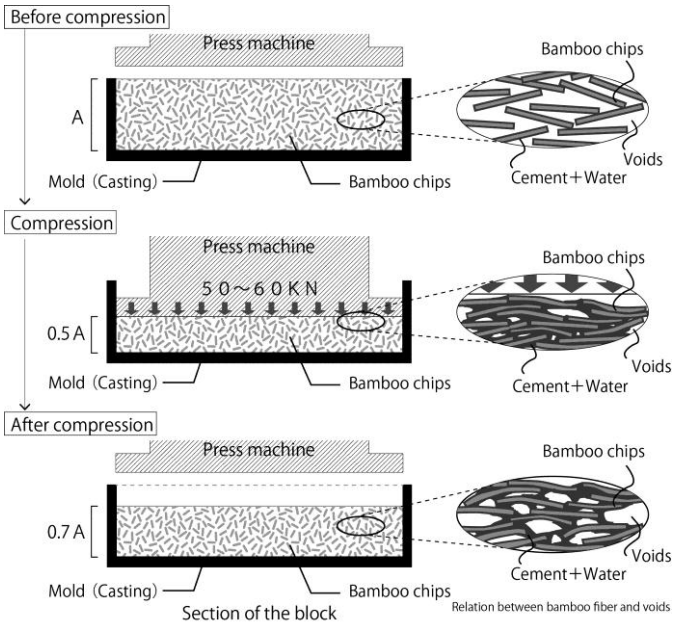

Fig -9: Compression process of bamboo fiber block and relationship between bamboo fiber and voids.

It is also beneficial to use white cement for the upper layer. The color of paving blocks made from white cement can be close to white. In addition, pigments can be added to white cement to create different-colored paving blocks. The color of the pavement is an important factor to attract pedestrians' attention and influences the atmosphere of the place.

In step 4, the material measured in step 3 is uniformly mixed by an Omni Mixer. At this time, it is possible to mix by Pan mixer. But, as bamboo powder has a low specific gravity, it is difficult to mix uniformly due to the tendency for lumps to form during stirring. In addition, if lumps are formed, it loses them before use.

In step 5, 90 mm of the material produced in Steps 1 and 2 for the lower layer is put into a mold with a height of 100 mm, then 10 mm of the material produced in Steps 3 and 4 is put on top of it. As the thickness of the coating layer increases, the weight increases. The materials inside of the mold are compression-molded by evenly applying compression of 50 to 60 KN with a press machine. The

upper coating layer is compressed and more densely compacted, but the thickness of the layer remains almost the same. As shown in Fig. 9, the lower layer is compressed to about 60 to 70 mm [10&11].

Compression molding makes it possible to mold bamboo chips with large fiber lengths. As a result, it is possible to produce a paving block that not only requires less bamboo fiber than molding with bamboo powder only but also has a flexible performance that takes advantage of the bending strength of bamboo chips. This block has high water permeability due to having high porosity.

The final step is demolding. It leaves for about 24 hours after compression molding and removal from the mold. Then, it cures and hardens for about 14 days. In addition, most of the strength comes out in about 14 days, but it is desirable to cure for 28 days.

The composition and manufacturing method of the bamboo fiber block described here was submitted to the Japan Patent Office on October 18, 2021, and a request was submitted for examination of the application on February 15, 2022 [10].

4. FEATURES OF THE BAMBOO FIBER BLOCK THROUGHOUT THE EXPERIMENT

4.1 Outline of the experiment

4.1.1 Material and its composition

Two types of cement, ordinary Portland cement and white cement, were used. In addition, bamboo chips and bamboo powder were used instead of fine and coarse aggregates (Fig. 1). Three types of admixtures were used: a high-performance AE water-reducing agent, a low-addition type expansive agent for concrete, and a coating-type high-performance shrinkage reducing agent. In the case of bamboo powder, the water-cement ratio was 30%. In the case of bamboo chips, the water-cement ratio was 40%. Tables 1 and 2 show a combination of bamboo powder and bamboo chips.

Table -1: Formulated with bamboo powder

W/C (%)	Unit of weight (kg/m³)		
	Water W	Cement C	Powder P
30	149	500	784

Table -2: Formulated with bamboo chip

W/C (%)	Unit of weight (kg/m³)				
	Water W	Cement C	Blowing agent B	Chip Cep	Admixture Ad
40	57	143	20	100	1.0

4.1.2 Testing method

Mixing was conducted using a mortar mixer for bamboo powder and an Omni mixer for bamboo chips. A mold sized

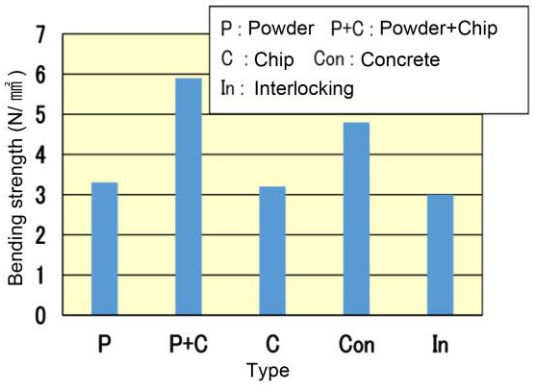

Chart -1: Relationship between bamboo type and bending strength

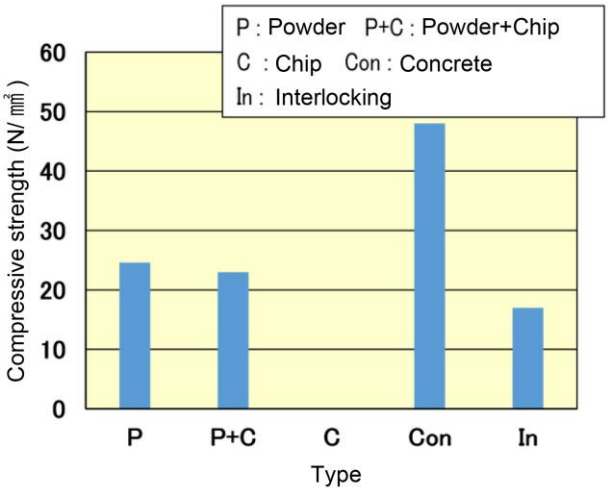

Chart -2: Relationship between bamboo type and compressive strength

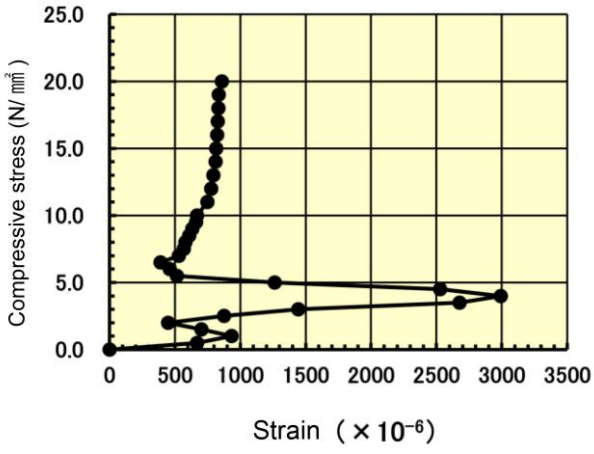

Chart -3: Stress-strain curve of the bamboo fiber block

100W×400L×100H mm was used to produce the sample pieces. Sample pieces consisted of three types: 1) bamboo chip block (C) 2) bamboo powder block (P) and 3) bamboo fiber block (C+P).

The bamboo chip block (C) consists of bamboo chips only. The bamboo powder block (P) consists of bamboo powder only. The bamboo fiber block (P+C) is composed of two layers mentioned in section 3. The first layer was bamboo chips on the bottom of the mold and the second layer was bamboo powder on the first layer.

By applying a pressure of about 60 KN, the test pieces of all types became approximately 100W× 400L×60H mm. After air-dried curing, bending strength and compressive strength were measured after 28 days according to JIS (Japan Industrial Standard) A 1106 and JIS A 1108. In addition, the strain was measured with a strain gauge while measuring the compressive strength.

4.2 Results and consideration of the experiment

4.2.1 Bending strength

According to quality standards of interlocking blocks for pedestrians mentioned by the Japan Interlocking Block Pavement Engineering Association (JIPEA), the bending strength must be 3.0 N/mm^2 or more. Chart 1 shows the bending strength of all bamboo block types, concrete, and interlocking blocks. It was confirmed that the bending strength of the bamboo chip block (C) generated by pulverizing waste bamboo satisfies the quality standard of 3.0 N/mm^2 or more for interlocking blocks for pedestrians (In) and was also confirmed to have sufficient compressive strength. In addition, it was found that the bending strength of the bamboo fiber block (P+C) is about twice as strong as the quality standard of the pedestrian interlocking block (In).

4.2.2 Compressive strength

Chart 2 shows the compressive strength. According to the quality standard mentioned by JIPEA, the compressive strength of the interlocking block for pedestrians (In) must be 17.0 N/mm^2 or more. The compressive strength of bamboo powder (P) is 24.6 N/mm^2 and the bamboo fiber block (P+C) had a compressive strength of 23.0 N/mm^2. Both were confirmed to meet the quality standards of the pedestrian interlocking block (In). In addition, the compressive strength of the bamboo fiber block (P+C) is about the same as that of bamboo powder (P), so no difference in strength is observed. However, as the density of the bamboo chip is decreased due to many voids in it, the strength is also decreased. Bending strength is not affected.

4.2.3 The strain of the bamboo fiber block

Chart 3 shows the stress-strain curves of the bamboo fiber block. It was confirmed that the strain increased in the initial stage, then decreased, and then increased again. The reason why the strain was lessened is that the bamboo fiber blocks have many voids, and when the voids apply pressure, the voids are clogged, and the strain becomes less.

4.3 Brief of the results of the experiment

The results of the experiment are the following:

(1) The bending strength of the bamboo fiber block was 5.9 N/mm^2, so that was confirmed to be sufficient as paving blocks for pedestrians. This outcome is due largely to the two-layer structure (bamboo chips and bamboo powder).

(2) The compressive strength of the bamboo fiber block was 23.0 N/mm^2, so that was confirmed to have sufficient strength. Furthermore, no difference in compressive strength between the two-layer structure and the powder alone was observed.

Fig -10: Production scenery of bamboo fiber block.

Fig -11: Laying bamboo fiber block.

Fig -12: Square paved with bamboo fiber block.

(3) The strain of the bamboo fiber block tended to be less at the initial stage and then increase again. The reason for this is that the voids were clogged, and the strain was reduced by applying pressure to the voids contained in the bamboo fiber block.

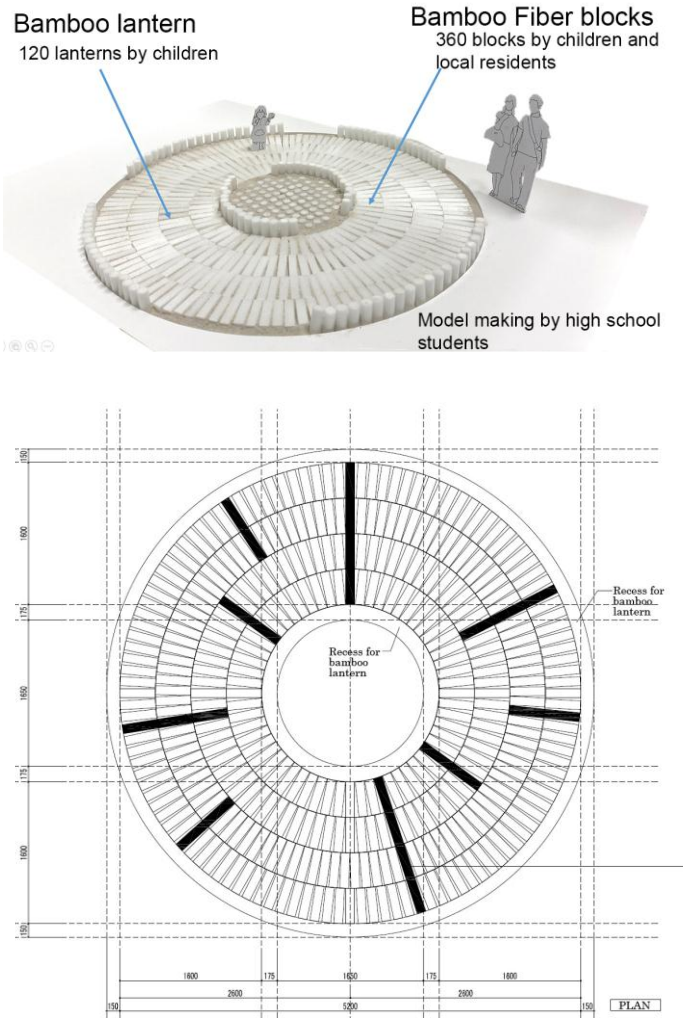

Fig -13: Model for composition plan of bamboo fiber block (upper) and its drawing (lower). Ground lights are installed in the black-painted areas on the drawing.

5. USE OF BAMBOO FIBER BLOCKS AND ADVANCED DEVELOPMENT

Bamboo fiber blocks were exhibited together with bamboo lanterns on vacant land in the Ietomi area, Ashikaga City, which was owned by the municipal cooperation of Ashikaga, from November 4th (Thursday) to 13th (Saturday) in 2021 (Fig. 10-13) [12].

Firstly, the ground was excavated to a depth of about 15 cm, the surface (10 cm of crushed stone was paved and rolled) was prepared, and about 340 bamboo fiber blocks were laid out. Furthermore, 120 bamboo lanterns were set around it. The bamboo lanterns were exhibited for two weeks. After that, the bamboo fiber blocks were continuously paved, and exposure tests were carried out for a year.

Problems such as cracks due to water permeability and drying shrinkage of bamboo fiber blocks and verification remain, and this study will continue in 2022.

6. CONCLUSION

This study began with the problem of abandoned bamboo groves, which has become a problem in the local community area. Then, the utilization of overlooked local resources considered. Abandoned bamboo groves were reused in the form of bamboo lanterns. In such a situation, bamboo fiber blocks were also produced.

Bamboo fiber blocks are more reasonable than conventional cement paving blocks and have the texture of natural resources and the flexibility of bamboo. The manufacturing method maximizes the flexibility of bamboo, applying bamboo fibers that are as long as possible. Long bamboo fibers are difficult to mold into blocks, but this can be overcome by compression molding. That is what makes the block even stronger. The features of the block in this research are summarized as follows.

1) Very light, 2) high flexibility, suitable for pedestrian pavement, 3) high water permeability and water retention, excellent heat-island effect, 4) the color of blocks can be adjusted while retaining the texture of bamboo. The features and effectiveness of the block were proven through experiments.

This research has just taken the first step; further verification is still required. Exposure experiments are currently being conducted for one year. Through experiments, the blocks on the site are being inspected for efficiency of water permeability and cracking due to the drying shrinkage of bamboo. Based on the experiment, efficiency can be improved further.

In addition, bamboo fiber blocks need to be replaced due to damage. However, they can be easily replaced by residents because they are lightweight and easy to handle. Moreover, damaged blocks can be easily broken into pieces and turned back into bamboo fibers and returned to nature. The eco-cycles of abandoned bamboo would also make use of a community development tool.

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SOURCES

Fig.1-13, chart1-3 and table 1&2: Author