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Design and construction of a bamboo structure waste treatment building

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ABSTRACT

This paper reports the design, construction, future maintenance plan of a glue laminated bamboo (glubam) building for a waste treatment and recycling facility. Bamboo is one of the important plants in the world, and it recently becomes a popular construction material. As one of the fastest-growing plants in the world, it can grow four feet within a 24-hour period. Compared with the traditional construction material, it has the advantages of regeneration and environmental-friendly. In the study, a small recycling facility was designed and constructed based on Standard for design of timber structures (GB 50005-2017). The recycling center is to collect the waste on the university campus. Besides bamboo, recycled aggregates were also used in the concrete foundation construction. To keep the building pollution-free, a set of solar system was designed to supply the electricity for the appliance in the recycling center. The design and construction of the waste treatment building meets the target of zero carbon emissions throughout the lifecycle of the building, and it gives a good example for the future glubam building construction.

1. INTRODUCTION

The rapid development of global industrialization has brought serious challenges to natural environmental protection. And the negative impact of the construction industry on the environment cannot be ignored. In China, the large-scale production and application of construction materials like concrete have caused a huge burden on the natural environment. Meanwhile, the vigorous development of construction industry comes with large amount of construction waste. If those waste cannot be handled properly, the natural environment will be further damaged. Under such background, there is a great demand for constructing green and environmentally friendly buildings in China. Thus, green materials, green construction methods, green system of operation and maintenance should be developed and analyzed.

In accordance with the basic requirements for green and environmentally friendly buildings, a small waste treatment building (Fig.1 and Fig.2) was designed and constructed based on Standard for design of timber structures (GB 50005-2017) on the Haining International Campus of Zhejiang University, China. The waste treatment building is analyzed from three perspectives of green construction materials, building structure and energy cycle. Glubam, a type of innovative construction material is used in construction. Its great performance on energy consumption and mechanical properties show its promising future in green construction industry (Xiao 2013).

Fig. 1 Waste treatment building on Haining Campus of ZJU

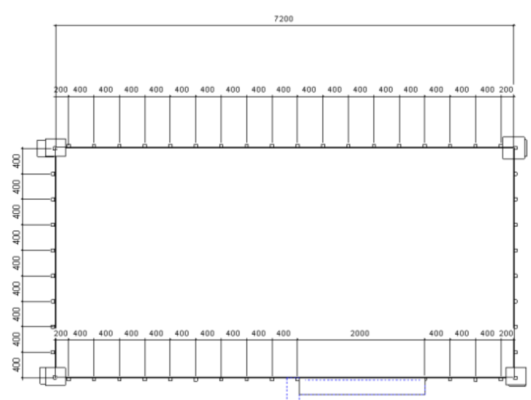

Fig. 2 Dimension for the floor plan

2. MATERIAL

Two types of environmentally friendly materials, glubam (glue laminated bamboo) and recycled concrete, are mainly used to build the recycling center structure. They both show great performance on recycling and sustainable properties.

Glubam is a new type of bamboo composite. It is a glue laminated bamboo similar to the wood based glulam. In China, though there exists a long history of bamboo usage, the application of bamboo composite in construction industry only started in recent years, following the popularization of concept of environmentally friendly building. Glubam is regarded as one of the prominent bamboo composites. It is related to all the aspects of construction including buildings, bridge (Xiao 2010). In addition, glubam also can be used to develop new types of space truss system with steel together (Xiao 2018). Compared with traditional construction materials, glubam has a many unique advantages. It has a renewable source and has short growth cycle. It performs well not only in mechanical properties but also in energy consumption and carbon dioxide emission. And its good mechanical performance leaves more space for engineers to design the buildings.

Recycled concrete is made by the waste concrete. The waste concrete should be undergoing complex procedures, including washing, crushing, and sieving based on a certain ratio to become recycled aggregate. By mixing those aggregate with other raw materials, recycled concrete is formed. Recycled concrete is of great importance for ecological protection construction. Western countries began to develop and apply recycled concrete technology in the late 1970s and have achieved great success. In comparison, research on recycled concrete in China started late. Although a series of technical accomplishments have been achieved, utilization rate of recycled concrete in China is less than 10%. China still has a long way to explore in the research and application of recycled concrete. Compared with natural concrete, the recycled concrete still has lots of drawbacks and related research should be made to improve its performance in practical application. In this project, the recycled concrete was used to build the foundation slab and the pedestal base for the glubam frame columns, as shown in Fig.3.

In addition to green construction materials, the solar-energy system is designed for the recycling center to help achieve the target of zero, or even negative carbon emissions throughout the life cycle of the building.

Fig. 3 Recycled concrete used in Recycling center

3. DESIGN

3.1 Design ideas

The structure system for the waste recycling center was designed based on main frame system as shown in Fig. 4. The original frame has the main column and girder covering the area of 3600 mm by 7200 mm. In the longer direction, the frame forms a single slope with the columns on higher side having a height of 3.5 m and the lower side of 2.5 m.

The structure was designed as a waste treatment building based on the dimension of the frame and the glubam material. Glubam has the function of removing odor producing by the garbage, and the dimension of the frame is suitable for a garbage truck to enter in. The garbage will transfer from the dormitory to the transfer station storing temporarily, and the garbage will be transferred to the refuse disposal plant later.

Fig. 4 Main frame

Enclosure system

For the design of the enclosure system, the roof is designed to use light-gauge steel sheets with 7.8 degree incline to help drainage. A 0.4m high hollow brick wall was designed and built around the building for aesthetic reason. The walls are sheathed with the low-grade timber plate strips.

Foundation

The recycled concrete was used to construct the foundation of the building. By mixing the recycled concrete with other types of raw materials, the strength of recycled concrete reached standard of C30. The thickness of the on-grade floor slab was 150mm.

Joint design

Joint design was an important part for glubam structure. The frame columns and beams were connected by using steel bolts with embedded steel plates, as shown in Fig.5a. Also, the purlins were connected with the main frame beams using steel angles and screws (shown in Fig.5b).

(a)

(b)

Fig. 5 Connections: (a) between beams and columns; (b) between purlins and beams.

Load Analysis

The load analysis is based on the probability based ultimate strength design method, similar to the Load and Resistant Factor Design. The loads applied to the structure are listed in Table 1, and Table 2 gives the load combination based on LRFD. The load values are calculated according to Chinese code “Load code for the design of building structures: GB 50009-2019”. The snow load and wind load are based on the data once in a century.

Table1. Load design value

	Load Value (kN/m2)
Dead Load (DL)	2
Live Load (LL)	4
Wind Load (WL)	0.5
Snow Load (SL)	0.5

Table 2. Load combination

	Load Combination	Load Value (kN/m2)
Case 1	1.4*DL	2.8
Case 2	1.2*DL+1.6*LL+0.5*SL	3.45
Case 3	0.9*DL+1.0*WL	2.3

The building was modeled as a frame structure with the columns pinned to the foundation.

4. ENERGY EFFICIENCY

Compared with the conventional building materials such as cement and steel, glubam has the great advantages in both energy consumption and carbon dioxide emission. Fig. 6 and Fig. 7 show the comparison between the energy consumption for different materials during manufacture. Data for glubam are from (Xiao 2013), data for cement are from Hammond and Jones (Hammond and Jones 2008), the others including timber, plywood, aluminum and structural steel are from Buchanan and Honey (Buchanan and Honey 1994).

As shown in Fig.6, glubam consumes much less energy than aluminum and steel, and it consumes comparatively small amount of energy compared with plywood and cement. Fig. 7 shows that glubam emit negative carbon dioxide during production, and it performs better than timber and plywood.

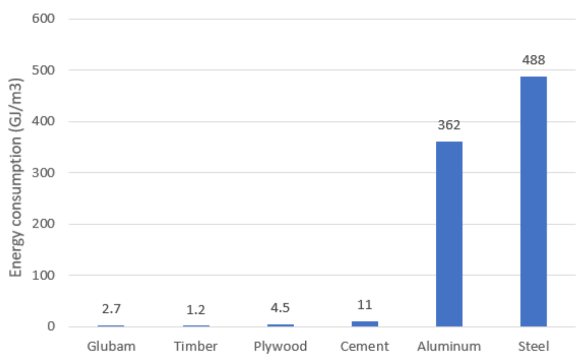

Fig. 6 Energy consumption for different material

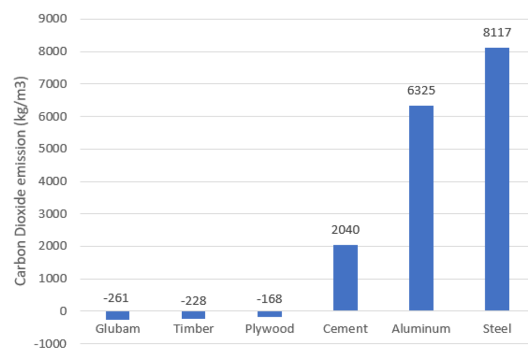

Fig. 7 Carbon dioxide emission for different material during manufacture

The waste recycling station used 3.2m^3 of glubam in total, Table 3 compares an analysis of energy consumption and carbon dioxide emission for different materials using the same amount of material, showing the environmental advantage of the building.

Table 3. Energy analysis for the structure

material	CO_2 emission (kg/m3)	energy comsumption (GJ/m3)
Glubam	-835.2	8.64
Timber	-729.6	3.84
Plywood	-537.6	14.4
Cement	6528	35.2
Aluminum	20240	1158.4
Steel	25974.4	1561.6

5. MAINTENANCE

In order to reflect the eco-friendly principle, solar system is designed to supply the energy. After analyzing the solar altitude angle, combining with the angle of the building's roof, 6 solar panels are designed to be installed based on the estimated electricity consumption.

A solar panel system includes polycrystalline 3A solar panels, inverters, distribution control boxes, batteries, and other components. There are six solar panels in total, with a total area of about 10m^2, thickness of 35mm, weight of 17.7kg, and can withstand 2400pa/5400pam wind and snow pressure load. Since the roof of the house faces north and slopes downward, the solar panels will be set towards south and installed through a tilting steel frame to improve utilization of the solar energy (optimal angle is about 30°).

The authors choose 5000W inverter for high-pressure water jets (1600W, inductive load), air quality meter (200W), fan (40W), and rolling door (200W) power supply. The solar panel has a daily output of 8 KWH and a continuous power supply time of 2~3 hours at maximum output, equipped with 4 batteries. With a maximum discharge capacity of 6 KWH, it can be charged and discharged at the same time.

Three power supply operating modes (conventional mode, energy-saving mode, solar-priority mode) meet different operating requirements and ensure the safety of use and longevity of the device. Normal mode prioritizes the use of mains power, with mains charging function. If power is down, it will use battery power. Energy saving mode automatically monitors the load. When the load is more than 5% of the rated power, the device is on and working; When no load is detected, the device automatically returns to search mode. The inverter enters the sleep state and turns off the output. It is worth mentioning that the inverter can be disconnected from the mains power supply in mode 03, which is "solar priority mode” and it can also be complementary to the mains power supply. This suits in multiple situations. The specific realization is to use the battery power supply priority. The utility does not charge, and only the solar charges. When in rainy days, solar energy is not full of battery, it will switch to utility power supply. When the energy is 80% full of battery, it will then automatically switch back to battery power supply.

6. CONCLUSION

As a demonstration of green construction, a waste recycling facility building was designed and constructed using glued laminated bamboo (glubam) and recycled concrete. The operation with solar power is also designed. The glubam and recycled concrete structure will also be used as a testbed for long term performance.

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