Transactions of the Materials Research Society of Japan 27 [3] 621-624 (2002)

Foamed *Chlorella*-PVC Composite as Sound Absorber and Thermal Insulator

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The purpose of this study is to make value-added composite using *Chlorella* powder discharged from the biological CO_2 fixation system and Polyvinyl chloride (PVC). The mixture containing PVC, *Chlorella* powder, Dioctyl phthalate (plasticizer), Ba-Zn-fatty acid compound (stabilizer), and Azodicarbonamide (foaming agent) was put in the glass vessel (or the metal mold) at the ratio of 100:20:75:3:10 on a weight basis, and heated up to foaming temperature about 200℃. After cool down the sample was removed from the vessel and measured sound absorption coefficient and thermal conductivity according to JIS. The sound absorption coefficient was 0.04～0.16 within 100～5,000 Hz of frequency. The sound absorption was so low that it could be applicable to sound insulator rather than sound absorber. The sound absorption coefficient was almost same as the typical sound insulator such as plaster board. The thermal conductivity was 0.064 W/m·K and showed same value as commercial thermal insulator like polystyrene foam.

This work was performed under the management of Research Institute of Innovative Technology for the Earth (RITE) as a part of the Biological Fixation and Utilization Project supported by New Energy and Industrial Technology Development Organization (NEDO).

Keywords : *Chlorella* sp., PVC, Sound absorber, Sound Insulator, Thermal Insulator

1. INTRODUCTION

Living organisms having chloroplast can fix CO_2 and make organic substances by photosynthetic function. Reduction of CO_2 emission into the atmosphere is very important issue for the sustainable development, because the increase of CO_2 in the atmosphere causes global warming. Research Institute of Innovative Technology for the Earth (RITE) has been conducted a research project of biological CO_2 fixation and utilization supported by New Energy and Industrial Technology Development Organization (NEDO) with participation of private companies from 1,990 to 1,999.

A large amount of micro-algae produced in the system should not make CO_2 appear again into the atmosphere by its utilization. As a member of the project Ishikawajima-Harima Heavy Industries Co., Ltd. (IHI) has been carried out the research and development for utilization of *Chlorella* for building materials with National Institute of Advanced Industrial Science and Technology (AIST), and has made *Chlorella*-polyvinyl chloride (PVC) composite [1], [2] and *Chlorella*-high density polyethylene (HDPE) composite[3]. The concept of the biological CO_2 fixation and utilization system was shown in Figure 1.

In this work we will describe the characteristics of the *Chlorella*-PVC composite as sound absorber and thermal insulator by foaming procedure to make their function more valuable.

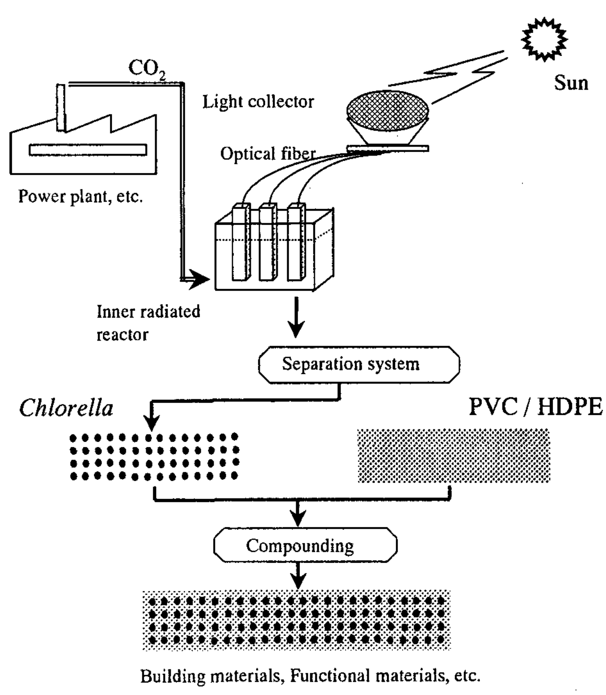

Fig. 1 Concept of biological CO_2 fixation and utilization system for eco-friendly materials

2. EXPERIMENTAL

2.1 Materials

Dried *Chlorella* powder (Yaeyama Ltd.) as the alternative of real photobioreactor products, PVC powder (n = 1100, Wako Pure Chemical Ind., Ltd.) were used in this work. Dioctyl phthalate (DOP) as plasticizer, Ba-Zn-fatty acid compound (PSE-227) as stabilizer, and Azodicarbonamide as foaming agent were added respectively.

2.2 Foaming and molding methods

The mixture of *Chlorella*, PVC, DOP, PSE-227, and Azodicarbonamide in a glass vessel with 100mm ϕ in diameter and 15mm in depth was heated up to foaming temperature about 200 ℃ in the electronic oven dryer after 15 minutes stirring. The outline of the method was shown in Figure 2. More large samples for measurement of the thermal conductivity were made using the metal mold of 200 × 200 mm of the Thermocompressor (NSF-37, Shinto Metal Industries Ltd.) limited the thickness up to 20mm.

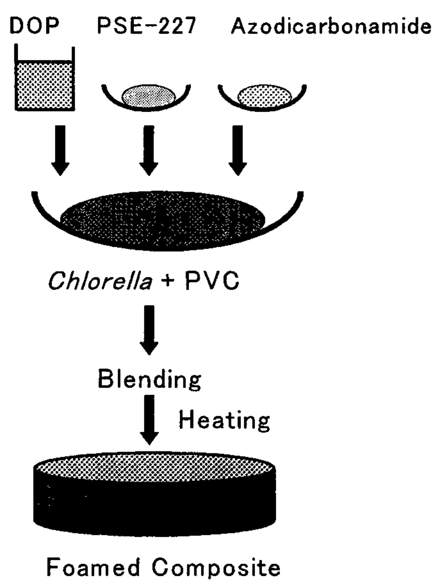

Fig. 2 Method for making of foamed *Chlorella*-PVC composite at a laboratory

The thin foamed composite samples were made at the mixing ratio of *Chlorella* and PVC, 0:100, 30:100, and 50:100 on a weight basis to evaluate the applicability to the cushion floor material. The foaming procedure was embrocation of the sample paste on the metal plate with free surface followed by heating at 200 ℃ for 2~4 minutes in the oven.

2.3 Mixing ratio for reparation of composite sample

We investigated some conditions for making optimum composite by varying amount of chemicals. Mainly the content of DOP, Azodicarbonamide, and *Chlorella* were changed to find good conditions with respect to foaming performance and elasticity. The mixture should be well blended and heated homogeneously to occur good foaming reaction.

2.4 Measurement

The test piece (foamed sample, 92~95mm ϕ in diameter) for the measurement was set in the impedance tube according to the standard method. The sound absorption coefficient was calculated as the ratio of incident sound pressure and reflected sound pressure on the surface of the test piece after the standing wave completed[4]. The sound frequency range used for measurement was 100~5,000 Hz. The concept of the method was shown in Figure 3.

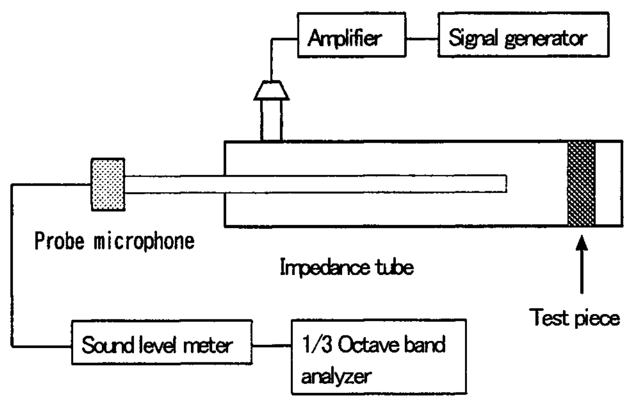

Fig. 3 Method of sound absorption coefficient measurement

The thermal conductivity was described as the thermal resistance ratio of the standard reference material and the test piece according to the standard method. Both of the test piece (foamed sample, 200×200×20 mm) and the standard plate sandwiched in between the high temperature plate and the low temperature plate were set in the temperature controlled bath as shown in Figure 4 [5].

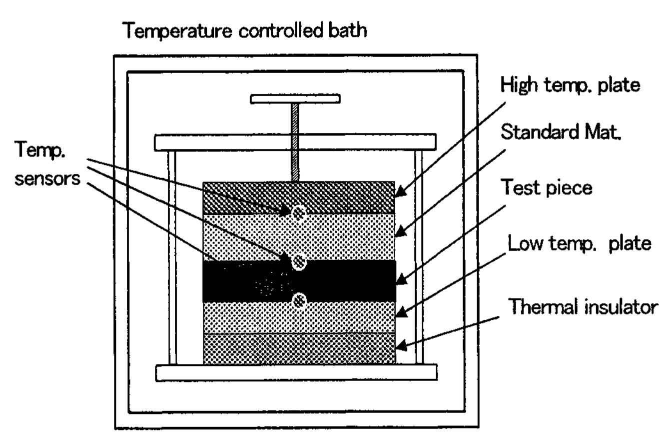

Fig. 4 Device for thermal conductivity measurement

An applicability of the thin foamed sample to the cushion floor material was evaluated by L value, which represents the percussive noise insulation level of a material. There are six L values, L-40 (best insulation) ~ L-65 (poor insulation) according to the Japanese Housing Loan Corporation.

3 . RESULTS AND DISCUSSION

3.1 Foaming and molding

The foaming mechanism was supposed to be gas generation by thermal decomposition of Azodicarbonamide. It produces N_2 gas etc. by heating which makes many air gaps in the composite over 180 ℃. As *Chlorella* content is larger, more color darkness of the composite increased, and elasticity was decreased. Table I showed the results of foamed composite production. It suggested the mixing ratio of the components, PVC 20g, DOP 15mL, PSE-227 0.6g, and Azodicarbonamide 2g, was best at the range of 4~10 g of *Chlorella* dosage.

3.2 Sound absorption coefficient of the foamed composite

From the results of Table I we measured the sound absorption coefficient of the sample, which contained 10g of *Chlorella* and 100g of PVC, and the sample of no *Chlorella* added as reference. The sound absorption coefficient of the both samples were 0.1~0.3 as shown in Figure 5 and it suggested the both were good sound insulator such as the plaster board.

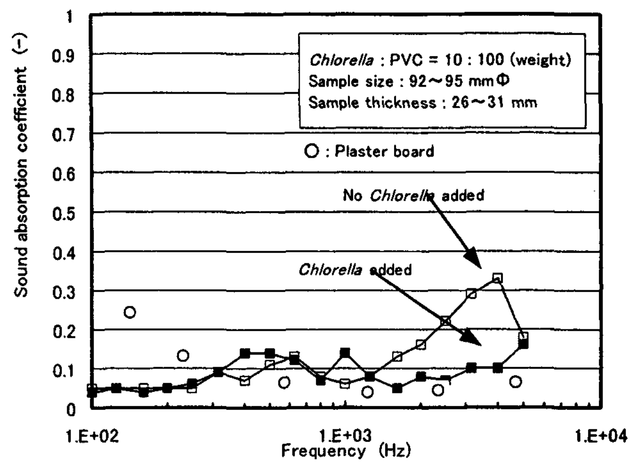

Fig. 5 Sound absorption coefficient of foamed *Chlorella*-PVC composite

3.3 Thermal conductivity of the foamed composite

The thermal conductivity of the sample (Chlorella : PVC = 50 : 100, 200×200×20 mm) was 0.064 W/m·K as shown in Table II and it showed same value as

Table I . Effect of compound ratio of foamed *Chlorella*-PVC composite Foam size S : small, M : medium, L : large

Sample	Compounding ratio					Foaming temp. ℃		Time	Evaluation		
No.	PVC	DOP	PSE-227	Azodicarbonamide	Chlorella	Set	Range	min	Foaming	Size	Elasticity
A-0	20g	15ml	0. 6g	0. 6g	—	195	186~195	20	×	S	△
A-1	20g	15ml	0. 6g	0. 6g	2g	195	185~195	22	×	S	△
A-2	20g	15ml	0. 6g	0. 6g	4g	195	183~195	19	×	S	△
A-3	20g	15ml	0. 6g	0. 6g	6g	200	190~200	18	×	S	△
A-4	20g	15ml	0. 6g	0. 6g	10g	210	199~210	20	×	S	×
A-5	20g	20ml	0. 6g	2g	6g	220	207~220	16	×	S	△
A-6	20g	15ml	0. 6g	2g	2g	210	198~210	13	△	S	○
A-7	20g	15ml	0. 6g	2g	4g	210	198~210	22	○	L	○
A-8	20g	15ml	0. 6g	2g	6g	210	199~210	20	○	L	○
A-9	20g	15ml	0. 6g	2g	10g	210	196~210	22	○	L	○
A-10	20g	15ml	0. 6g	1g	—	210	198~210	15	○	L	○
A-11	20g	15ml	0. 6g	1g	2g	210	198~210	18	○	M	○
A-12	20g	15ml	0. 6g	1g	4g	210	197~210	19	○	M	○
A-13	20g	15ml	0. 6g	1g	6g	210	197~210	19	○	L	○
A-14	20g	15ml	0. 6g	0. 6g	—	200~220	190~210	22	○	M	○
A-15	20g	15ml	0. 6g	0. 6g	2g	200	179~200	35	×	S	○
A-16	20g	15ml	0. 6g	0. 6g	4g	200	185~200	30	○	S	○
A-17	20g	15ml	0. 6g	0. 6g	6g	200	185~200	30	△	M	△
A-18	20g	15ml	0. 6g	0. 6g	10g	200	186~200	40	×	S	△
A-19	20g	20ml	0. 6g	1g	6g	200	184~200	30	○	S	○
A-20	20g	15ml	0. 6g	2g	6g	200	185~200	28	○	M	○
A-21	10g	8ml	0. 6g	0. 3g	—	195	179~195	43	○	M	○
A-22	30g	25ml	0. 6g	0. 9g	9g	195~220	183~215	33	△	S	○

commercial thermal insulator like polystyrene foam (0.03~0.04 W/m·K), urethane foam (0.03 W/m·K), or castable refractory (0.12~0.24 W/m·K).

Table II. Thermal conductivity of foamed *Chlorella*-PVC composite

Test piece	No *Chlorella* added	*Chlorella*:PVC=50:100
Size (mm)	200×200	200×200
Thickness (mm)	About 12	About 20
Method	Probe method	Heat flow meter method
Mean temp. (°C)	—	19.6
Temp. difference (K)	—	18.4
Thermal conductivity (W/m·K)	0.088	0.064

3.4 Percussive noise insulation of the foamed composite

The sample of *Chlorella* : PVC = 30 : 100 indicated foaming magnification 4.0 (about 3 mm in thickness) as shown in Figure 6, it suggested L value of the thin foamed sample attached with the foamed underlayer was 50, intermediate value of the cushion floor material according to the Japanese Housing Loan Corporation.

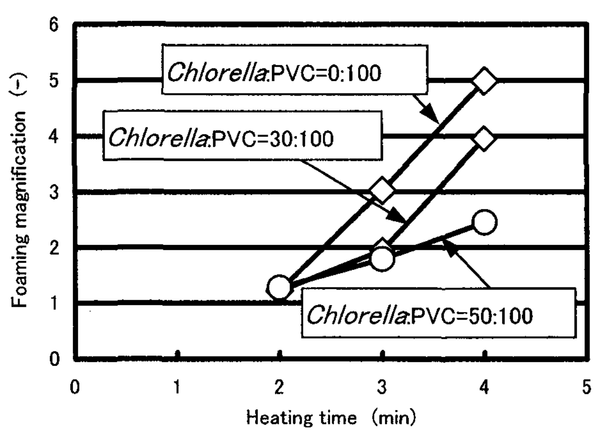

Fig. 6 Effect of *Chlorella* content on foaming magnification of the composite Temp. 200℃, Initial thickness 0.7 mm

4. CONCLUSION

The sound absorption coefficient was 0.04~0.16 within 100~5,000 Hz of frequency. The sound absorption was so low that it could be applicable to sound insulator rather than sound absorber. The sound absorption coefficient was almost same as the typical sound insulator such as plaster board.

The thermal conductivity was 0.064 W/m·K and showed same value as commercial thermal insulator like polystyrene foam.

The L value of the thin foamed composite was almost 50 (L-50) which means people in a room do not mind the noises such as dropping spoon through the floor of the above room when the composite is used with the thickness of 4.2 mm.

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(Received December 21, 2001; Accepted May 31, 2002)