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Construction utilization of foamed waste glass

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Abstract: Foamed waste glass(FWG) material is newly developed for the purpose to utilize the waste glassware and other waste glass. FWG has a multi-porous structure that consists of continuous or discontinuous voids. Hence lightweight but considerable stiffness can be achieved. In the present study, the manufacture and engineering properties of FWG are introduced first. Then, the utilizations of FWG are investigated in laboratory tests and field tests. Some case studies on design and construction work are also reported here. Through these studies we know that the discontinuous void material can be utilized as a lightweight fill material, ground improvement material and lightweight aggregate for concrete. On the other hand, the continuous void material can be used as water holding material for the greening of ground slope and rooftop, and as clarification material for water.

Keywords: foamed waste glass(FWG); engineering properties; lightweight material; construction

Introduction

Nowadays, aiming at achieving a sustainable development, methods of processing waste have become a global problem. Consequently, the amount and the ratio of recycling waste have been increasing within various fields for years. In Japan, the annual discharge of general waste and industrial waste in 1997 were nearly 50 million-ton and 400 million-ton respectively. The production of glass bottles in Japan was about 1.98 million-ton in 1998, and about 73.9% of the production, namely 1.46 million-ton, was used as collets. The amount and the ratio of recycle have been increasing for years, however more utilization has to be promoted.

The research, motivated by above social situations, will make clear the engineering properties of a foaming waste glass material(FWG) which was newly developed from waste glass bottles and other waste glasses, and investigate on its various utilization. A lot of utilization can be considered as shown in Fig. 1.

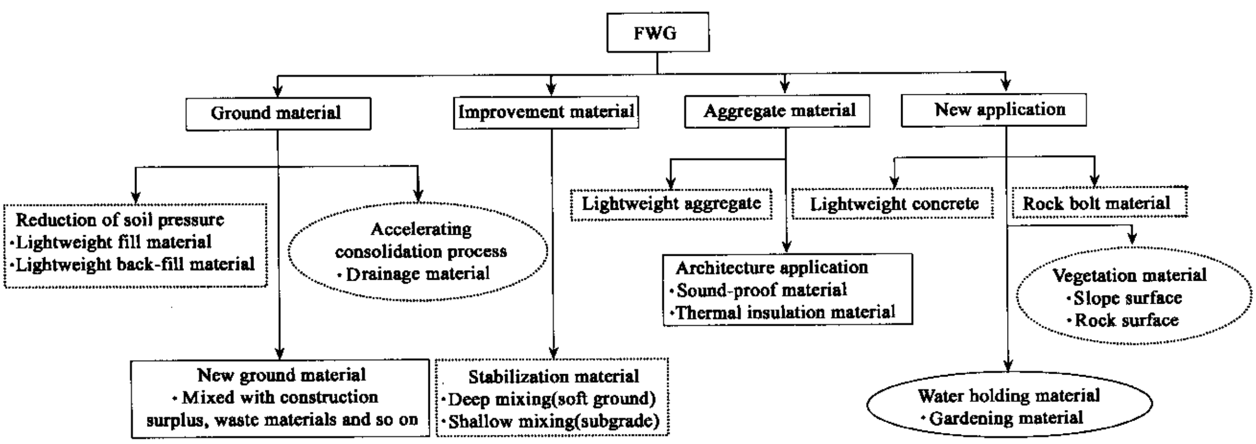


Fig.1 Utilization of FWG

1 Properties of FWG

FWG is produced in the following process: (1) collected waste glass is crushed to a powder size of 10 - 100 micrometers or less; (2) glass powder is mixed with the foaming agent; (3) mixture is melted for 5—60 min at the temperature of 700—1000°C.

FWG has a porous structure with numerous macro and micro voids. Hence, this material is light and considerably stiff. The specific gravity can be controlled by condition of process ranged from 0.3 to 1.5. In addition, the water absorption of the material is also changeable. Two kinds of void structure are available, which are discontinuous and continuous void structures. The discontinuous void material shows less water absorption, whereas the continuous void material shows high water absorption. FWG with these two kinds of voids but the same specific gravity, 0.4, are shown in Fig. 2 and 3. Fig.2a shows the out appearance of FWG with discontinuous void. Due to mere surface absorption the water absorption percentage is only 5.8%, a little higher than that of ordinary sand, 1%—3% and gravel, 0.5%—2%. Fig.3a is the FWG with continuous internal void, and the water absorption ratio is as large as 25.8%. The scanning electron microstructure (SEM) of FWG (70 times) is also shown in Fig. 2b and Fig. 3b.

Table 1 shows the engineering properties of the FWG material of specific gravity 0.4 with discontinuous void, which is less water absorption.

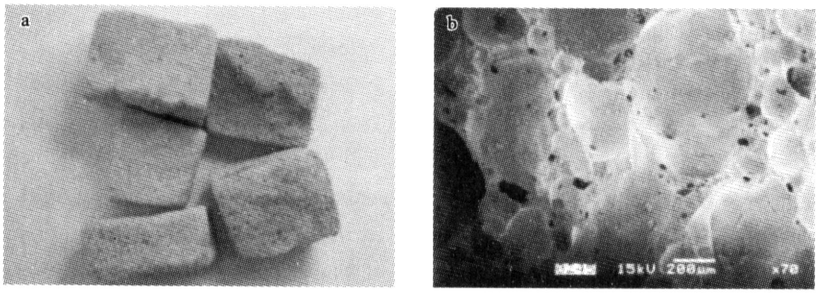


Fig. 2 Outward appearance and microstructure of FWG with discontinuous voids

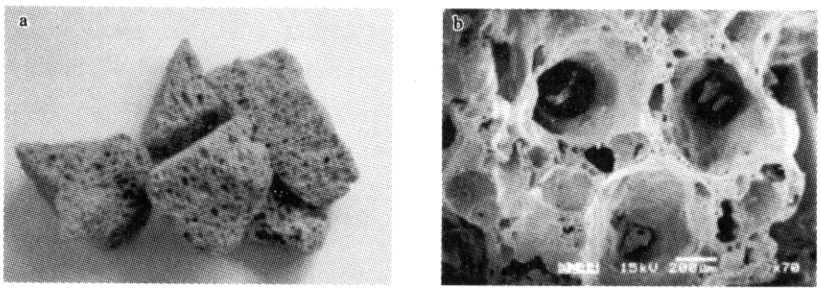


Fig. 3 Outward appearance and microstructure of FWG with continuous voids

Table 1 Some properties of FWG (specific gravity 0.4)

Test items \ FWG samples	Original FWG	Compacted FWG by different energy, E_c					
		0	0.50	0.75	1.00	2.00	4.00
Water content, %	0						
Gravel, %	100		93		85	76	70
Sand, %	0		3		8	14	17
Silt and clay, %	0		4		7	10	13
Dry density, g/cm^3	0.183	0.185	0.265	0.288	0.321	0.369	0.456
Water absorption, %	5.8						
Coefficient of permeability, cm/s				0.19×10^0			
Unconfined strength, kN/m^2	2750—4650						
Triaxial test: c, kN/m^2	18.6			77.5			
Triaxial test: ϕ, degree	29.5			32.6			
CBR test: expansive content, %	0.005*	-0.023		-0.001			
CBR test: water absorption, %	38.7*	21.5		21.5			
CBR test: average of CBR, %	30.9*	2.6		17.7			
pH		8.0		9.8			11.0
Unit weight, g/cm^3	0.233						
Abrasion test: percentage of wear, %	50.4						
Slaking percentage, %	0.1						
Crushing test: percentage of passing, %	32.6						

Note: * Design CBR ($1.81E_c$, $E_c = 0.552$ J/cm^3)

2 Utilization of FWG as construction materials

2.1 Lightweight materials

Fig. 4 illustrates examples of utilization of FWG as lightweight fill materials. When FWG is used as a lightweight fill material, it has the following characteristics.

(1) Because of the raw material is made of glass, FWG is resistant to heat or chemicals.

(2) FWG does not contaminate ground or ground water due to no harmful materials do leach out.

(3) Because the specific gravity is adjustable, FWG of a certain specific gravity corresponding to the specific ground condition is available.

(4) The weight is constant even under rainfall because

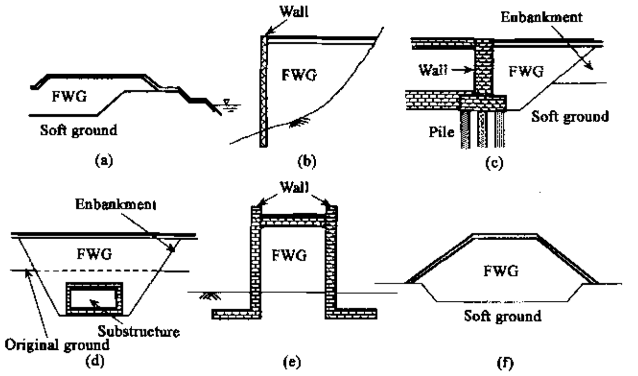


Fig.4 Examples of utilization of FWG as lightweight fill materials
(a) Reduction of settlement and prevention of slope failure of the embankment; (b) Reduction of weight and soil pressure of the fill in mountainous area; (c) Reduction of differential settlement at the structure connection; (d) Reduction of vertical soil pressure on the substructure; (e) Reduction of horizontal pressure on the two sides; (f) Reduction of settlement and prevention of slope failure on soft ground

of its little water absorption; meanwhile the permeability is high.

(5) The shape and size of FWG are similar to ordinal gravel or crushed stones, so the material can be filled and compacted in the field similarly to ordinal geo-materials without using any special construction machine.

Herein we introduce a case study of design using FWG materials for a restoration of a failed slope due to rainfall in Karatsu City, Saga Prefecture, Japan(Sato, 2002). The site of the project is a failed slope in the middle of the hill land (Fig. 5), which is now stable with an angle of the slope reaching less than 45 degree. The base part of the slope is Higashi matsuura-granite and the surface is a thin layer of deposit basalt and granite aggregates. In geography and geology point of view, the failed slope is located at the bottom place of a valley where it is easy to gather rainfall seeping into the slope. As shown in Fig.5, due to gradually losing sands under the foundation caused by rainfall, the building at the top, the slope were becoming more and more dangerous. A design of using FWG as lightweight fill materials was performed aiming at stabilizing the building foundation and restoration of the failed slope.

The planning slope section is illustrated in Fig. 5. Then, stability analysis of the slope and the gravity retaining wall when FWG and the field soil are utilized as back fill materials respectively are carried out. Stability analysis is carried out by means of Fellenius method and the safety factor of slope stability is assumed be 1.20.

Results obtained in stability analysis of the designing slope using field soil and the FWG materials are shown in Table 2. As shown in the table we can note that in the case of utilizing FWG both the slope and the gravity retaining wall can satisfy the demand of stability. On the contrary, using field soil as back fill may be dangerous.

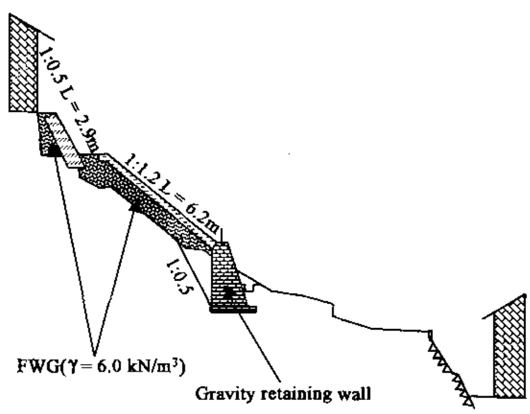


Fig. 5 Cross section of the slope after restoration

Table 2 Results of stability analysis

	Analysis items	Stability requirements	Field soil	FWG
Gravity	Eccentric distance, m	< 0.33	0.52 Unsafe	0.11 Safe
retaining	Safety factor of slip	> 1.5	0.82 Unsafe	2.13 Safe
wall	Vertical stress on ground, kN/m^2	< 100	256.6 Unsafe	92.9 Safe
Slope	Safety factor of slide	> 1.2	0.88 Unsafe	3.79 Safe

Based on the above analysis results, the FWG material, which has lighter weight and greater strength than the field soil, is adopted in this lightweight fill construction.

As mentioned previously, since this site is a place where surface water due to rainfall is easy to gather it is expectant that drainage of early stage will be faster than before owing to the higher permeability of FWG material.

2.2 Subgrade or sub base improvement materials

2.2.1 Utilizing FWG and quick lime

In order to improve a soft subgrade under the pavement, the foaming waste glass and a quick lime were mixed into the soft soil and some laboratory tests on the mixtures were carried out(Onitsuka, 1999).

The soft subgrade, is a decomposed basalt "Onjyaku" in Matsuura County, Saga Prefecture as shown in Table 3. The design CBR of the subgrade is only 0.2%, so that it must be improved to achieve a required bearing capacity.

The soft subgrade soil with natural water content was mixed with FWG material and quick lime. The laboratory CBR test was carried out on the mixed soil samples according to JIS A 1211(Japan Geotechnical Society). Three mixtures were tested, i.e. case 1: only FWG, case 2: only quick lime, and case 3: FWG and quick lime(Table 4).

Fig.6 indicates the CBR test results. For case 3, we attribute both the decrease of water content due to hydration of quick lime and modifying of grain grading as the reasons of the improvement effects. Based on the results of case 3, the depth of subgrade needed to obtain the aimed design CBR of 4% from the existing value of 0.2 % as mentioned above, are calculated as 55, 40, 34 cm corresponding to the mixing ratio of 7%, 10%, and 13% respectively.

Table 3 Properties of the subgrade soil

Specific gravity	2.823
Natural water content, %	52.3
Maximum grain size, mm	19.0
Grain size distribution	
Gravel, %	16.3
Sand, %	24.9
Silit, %	34.7
Clay, %	24.1
Liquid limit, %	57.8
Plasticity index	15.4
Maximum dry density, g/cm^3	1.332
Optimum water content, %	35.3
Classification	CH
Design CBR, %	0.2

Table 4 Mixing ratio of improvement materials

	Stabilizer	Mass percentage to dry soil, %		
Case 1	FWG	7.0	10.0	13.0
Case 2	Quick lime	7.0	10.0	13.0
Case 3	FWG	3.5	5.0	6.5
	Quick lime	3.5	5.0	6.5

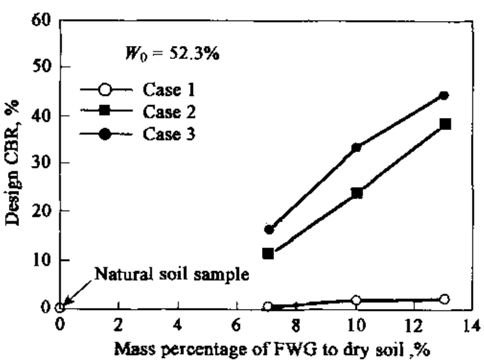


Fig. 6 Improved design CBR with FWG and quick lime

2.2.2 Utilizing FWG and cement

Herein we introduce an example of improving relatively soft ground just around the base of highway bridge pier with FWG material and cement (Onitsuka, 1999). The soil properties are as follows: natural water content $w_n = 27.0\%$, void ratio $e = 0.94$, plasticity index $I_p = 17$. The design strength q_u is 98 kN/m^2. With consideration of severe design condition the required strength is supposed as three or four times of the laboratory strength, i.e. 392 kN/m^2. From the unconfined compression test as shown in Fig. 7, cement content 50 kg/m^3 and FWG content 75 kg/m^3 were adopted. After the improvement, by carrying out a plane-loading test it was confirmed that the improved ground had an enough bearing capacity.

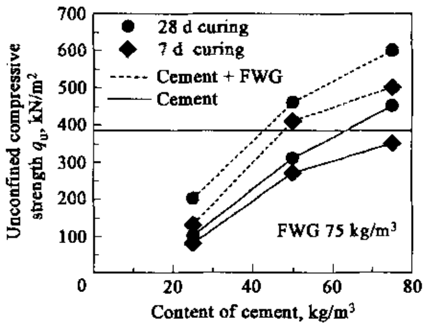


Fig.7 Improved unconfined compression strength with FWG and cement

2.3 Improvement materials for surplus soft clay

Ariake clay is well known as very soft and sensitive clay, which extensively distributes around Ariake bay, northern Kyushu, Japan. The properties are shown in Table 5. A huge amount of surplus Ariake clay due to construction projects appears every year. In order to reuse the surplus Ariake to make a sound ground material, stabilizers such as quick lime and cement are utilized often. In this research FWG material is added to Ariake clay with quick lime and fly ash (coal ash) (Onitsuka, 2002). Grain size of FWG material used here range from 2 to 4.75 mm.

Table 5 Properties of Ariake clay

Specific gravity	2.54
Natural water content, %	110—130
Grain size sistribution	
Gravel, %	0.0
Sand, %	37.0
Silit, %	44.0
Clay, %	19.0
Liquid limit, %	89.5
Plastic limit, %	39.6
Plasticity index	49.9
Ig. loss, %	7.4

Specimens of different mixtures, i.e. LAG (lime-ariake clay-FWG), L AF (lime-ariake clay-fly ash), and LAFG (lime-ariake clay-fly ash-FWG) mixture are made in cylinder moulds, 5 cm in diameter and 10 cm in length. Fig. 8 shows the relationship between the compressive strength q_u of the LAG mixture and content of FWG after 7 d curing. An evident increase in the q_u can be achieved by increasing the content of lime. For higher lime content more than 10%, increasing the content of FWG can lead to apparent increase of q_u.

2.4 Lightweight concrete aggregate materials

Through the aforementioned introduction of FWG properties it is not difficult to call to mind that FWG can be used as a lightweight aggregate of concrete products. In fact such attempts have been conducted. Herein we give two examples (Yokoo, 1999). Example 1 is a reinforced concrete anchor board using in slope stabilization project and example 2 is an anti-avalanche block (Fig. 9). Table 6 illustrates some details of there two examples.

In addition, owing to adopting FWG as concrete aggregate, mass of the anchor board in example 1 was reduced to 550 kg(unit mass 1.75 t/m^3) from 760 kg for conventional aggregate concrete, while mass of the anti-avalanche block in example 2 was reduced from 77.5 kg to 55 kg(unit mass 1.75 t/m^3) due to the same reason. The new concrete block mass is nearly two third of the conventional concrete block. Hence, the construction of these new concrete blocks becomes easier and the transportation fee becomes cheaper.

2.5 Water holding materials for greening

It has been proved by experiments that FWG with continuous voids can absorb so much water that is equal to 1.4 times of FWG dry weight. Due to this exceedingly good

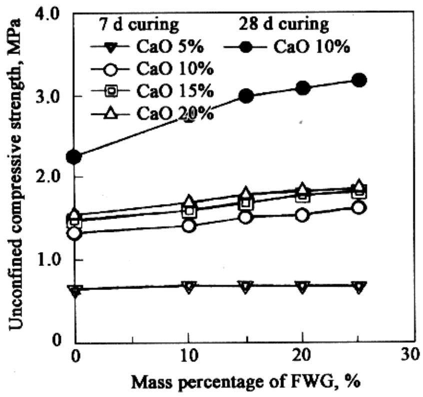
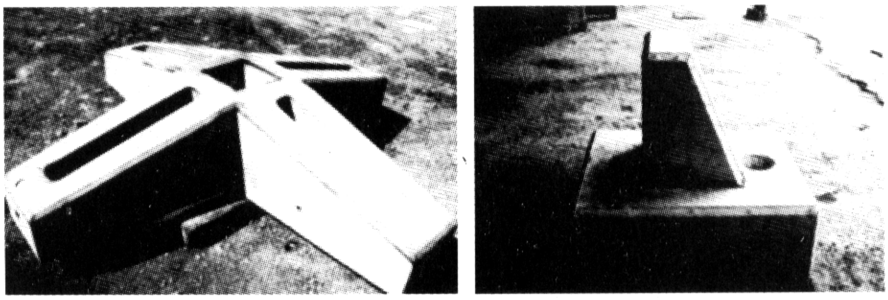


Fig. 8 Effects of FWG on unconfined compressive strength



(a) Reinforced concrete anchor board (b) Anti-avalanche block

Fig. 9 Two examples of lightweight concrete products

Table 6 Mixing ratio and compressive strength

	Mass unit volume, kg/m^3					Compressive test		
							Strength, MPa	
	Water	Cement	Fine aggregate		FWG	Sample size	7 d	28 d
Example 1	205	457	674		297	ϕ10 × 20 cm	23.6	30.8
Example 2*	166	340	244	569	218	ϕ10 × 20 cm	31.2	37.8

Note: * . two kinds of fine aggregate were used in example 2

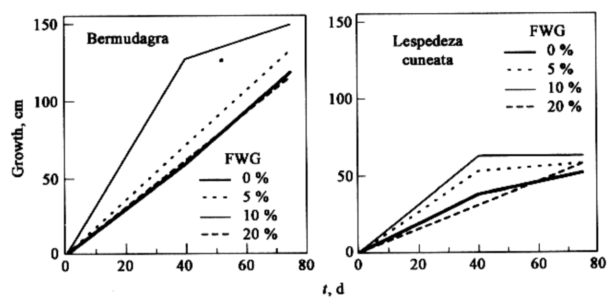


Fig. 10 Comparison of plant growth in FWG mixture

absorption property FWG with continuous voids is regarded as a good water holding materials for greening. Two examples of utilization as a water holding material in new greening technique will be discussed in this section.

In order to guard against slope failure due to rainfall, greening of the slope is necessary. In a slope stabilization project in Saga Prefecture, Japan, FWG was adopted as water holding material for greening the slope, where FWG of 5—25 mm in grain size was planned to be mixed with slope base soil (mainly composed of gravel soil), fertilizer, and adhesive material to form the greening base soil (Hara, 1999). In order to determine the appropriate mixing ratio of FWG two kinds of plants were selected which were Bermudagrass and Lespedeza cuneata, and some tentative tests were conducted. Fig. 10 shows the growth of these two plants with different FWG mixing ratio. We can note that in cases of FWG mixing ratio 5% and 10% growth of these two plants are enhanced. Especially 10 % FWG content seems the most suitable for the greening of gravel soil slope.

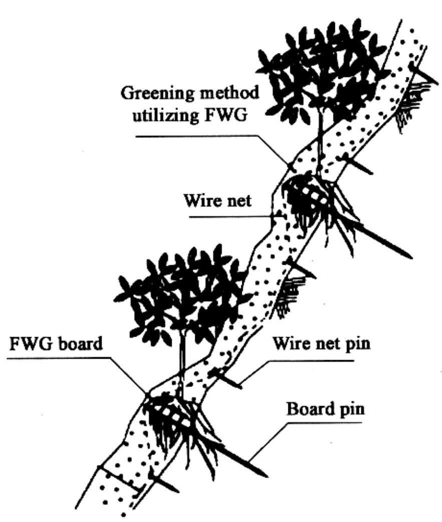
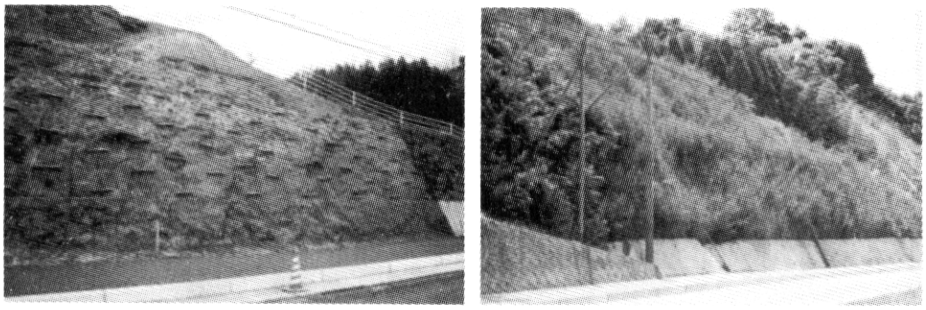


Fig. 11 Greening technique utilizing FWG board

Second is an example using FWG as water holding materials for greening of a rock slope, where FWG boards (8.0 cm in width, 50.0 cm in length and 1.0 cm in thickness) were fixed on a rock slope(Fig. 11). This special board is made from cement and FWG with continuous void, which is of 15—40 mm in grain size. Hence the board is light and excellent in both water holding ability and rustproof. By fixing these boards horizontally and in zigzag on the rock slope, it is expected these boards will prevent slides of the borrow soil. Meanwhile since FWG in the boards bear exceedingly good absorption property of water, even if the slope surface soil becomes dry, there is still plenty of water in FWG that can be supplied to the surrounding soil and plant roots(Fig.12).



(a) Construction of FWG board on rock slope (b) Greening effect after construction

Fig.12 Field condition of greening technique utilizing FWG board on rock slope

3 Conclusions

FWG is a new material made of waste bottles and other glasses. The specific gravity of FWG can be adjusted from 0.3 to 1.5 according to production condition. Meanwhile FWG with continuous and discontinuous void structures are also available, which leads to various utilization of FWG. In the present research we first introduced some basic properties of FWG and then gave some laboratory tests results and practical construction examples of utilizing FWG. The following lists the main utilizations of FWG in construction by now in Japan (1) lightweight fill material; (2) subgrade or sub base improvement materials; (3) improvement materials for surplus soft clay; (4) lightweight concrete aggregate materials; (5) water holding materials for greening.

From this paper we can see that FWG bears excellent and distinct engineering properties that might be applied to various construction projects. Moreover, since this is a recycle material, effective utilization of FWG can contribute to greatly reduce the environmental impact of modern society.

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