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Reclamation of Inorganic wastes to Artificial Lightweight Aggregates

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Annually, Taiwan generates approximately 2 million tons of inorganic wastes in the form of sludge, fly ash and slug. To increase the added value of waste and maintain the increasingly insufficient supply of natural gravel, large public construction projects account for this large demand each year. Future architectural trends are leading towards high-rise buildings.

In light of the above, Center for Environmental, Safety and Health Technology Development, Industrial Technology Research Institute has developed the technology of manufacturing cold-bonding, sintering and bloating types of lightweight aggregates with a specific gravity ranging between 0.7~1.7, water absorption rate < 30%. The lightweight aggregate verified by physical property tests can be used as a substitute for the natural aggregate, which generally appears in replacing gravel in concrete, soundproofing and heat insulation materials. Doing so would not only moderate waste disposal problems, but also achieve the goal of resource recovery.

Keywords: Lightweight aggregate, Cold-bonding, Sintering, Bloating.

INTRODUCTION

Reserves of natural gravel in Taiwan have become exhausted because of over excavation. Inorganic wastes from coal fly ash, paper sludge, stone material sludge and dam sediment has been increasing, reaching roughly 2 million tons per year, and representing 13~17% of total industrial waste. The shortage of natural gravel and the increase of inorganic wastes have both become serious problems for Taiwan. The best way to solve the problems is to develop technology to manufacture aggregates from inorganic wastes. In view of this, we spent three years on researching such technology. This technology can successfully change inorganic wastes to lightweight aggregate to maintain the ever-dwindling supply of natural gravel for large public construction projects each year and also increases the added value of inorganic waste.

Estimating the lightweight aggregate containing cold-bonding, sintering and bloating types of lightweight aggregate requires capacity of the building construction about 300,000 tons per year and creates output valued at around one billion NT dollars. (31million US dollars) The Taiwanese government also legislated to encourage waste resource and recovery on July 19, 1995. Now is the critical time for developing the artificial lightweight aggregate technology for its practicability as well as its necessity.

PREPARATION AND EXPERIMENT

MATERIAL OF THE EXPERIMENT

1.Coal fly ash: (Table 1 lists the Toxicity Characteristic Leaching Procedure (TCLP) for Coal fly ash.) The coal fly ash is produced by the Taipower Company. In 1995, the rates for usage exceeded 79.6% of Coal fly ash, reaching a total of 970 thousand tons. However, since the carbon content of the Coal fly ash exceeds 13%, it does not meet the quality requirements for a partial replacement for cement, since its instability can not win the complete trust of consumers. The amount of usable Coal fly ash is limited, and further study is required to produce the high quality products to increase consumption of consumers.

Table 1. Toxicity Characteristic Leaching Procedure (TCLP) for Coal fly ash

Sample / Analysis Items	Coal fly ash (1)	Coal fly ash (2)	Average	EPA Regulation
Zn(mg/L)	0.25	0.58	0.44	–
Cu(mg/L)	0.13	1.00	0.57	15.0
Pb(mg/L)	0.13	0.53	0.33	5.0
Cd(mg/L)	0.02	0.09	0.06	1.0
Cr(mg/L)	0.06	0.06	0.06	5.0

2.Paper sludge: (Toxicity Characteristic Leaching Procedure (TCLP) for Paper sludge is see table 2.) In Taiwan, the wastewater treatment units of paper mills generate 500 tons paper sludge daily, containing 75% water. Some domestic paper manufactories have developed sludge incineration systems to reduce sludge. However, the paper sludge contains 70% organic fibers and 30% inorganic clay materials, with their thermal energy generally being recycled via incineration. Following incineration, the ash can be converted into organic fertilizers and construction materials. To elevate the added value to paper sludge, both ash and paper sludge are used as materials for producing the lightweight aggregates herein.

Table 2. Toxicity Characteristic Leaching Procedure (TCLP) for Paper sludge

Sample / Analysis Items	Paper sludge (1)	Paper sludge (2)	Average	EPA Regulation
Pb(mg/L)	0.41	0.69	0.55	5.0
Cd(mg/L)	0.02	0.03	0.03	1.0
Cr(mg/L)	0.11	0.21	0.16	5.0
Cu(mg/L)	0.01	0.03	0.02	15.0
Zn(mg/L)	1.62	1.48	1.55	–
Hg(mg/L)	ND	ND	–	0.2
As(mg/L)	ND	ND	–	5.0

footnote : ND show not detectable.
The detection limit of [Hg] is 0.5μg/L.
The detection limit of [As] is 0.1mg/L.

3.Dam sediment: The dam sediment from the Shi-Men Dam in Taoyuan County also serves as a raw material for lightweight aggregates. The dam sediment comes from upriver and is brought down by rain over the years. The sediment already filled 13 pools by 1998. (Fig. 1. The ground plan of Shi-Men Dam sediment pools) The average capacity of sediment pool is 200,000 cubic meters, with a total volume of around 2.6 million cubic meters. The sediment in the pools needs to be removed to maintain the capacity of the dam. (Table 3 lists the data on the constituents of the sediment from the Shi-Men Dam.) The sediment comprises bloating clay and shale, which contain natural bloating substances to form lightweight aggregates. This study took 20 samples from the head, middle and tail region of 13 pools (see Fig. 1). The total weight of the samples was 1,000kg. Following drying and grinding, the samples were tested and the results recorded. The particle size of the sediment ranged between 0.1~50μm, with the average being 4~5μm. (Table 4 lists the particle size distribution of Shi-Men Dam sediment pools Nos. 1 and 3.)

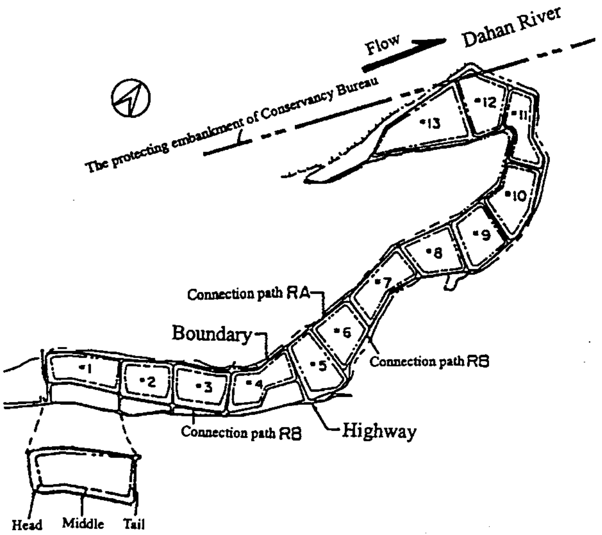


Figure 1. The ground plan of Shi-Men Dam sediment pools

Table 3. The constitute analysis data of sediment from Shi-Men Dam

Constitute / Region	L.O.I. (%)	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	K_2O (%)	Na_2O (%)	MgO (%)	CaO (%)
Head	4.86	65.86	16.25	6.20	3.05	1.61	1.61	0.47
Tail	6.10	58.27	20.67	7.09	4.13	1.31	1.88	0.49
Middle	6.58	57.80	20.99	6.96	4.00	1.12	1.67	0.86

Table 4. The particle size distribution of Shi-Men Dam sediment pools No.1 and No.3.

No.1.	Particle size distribution (μm)	0.3	0.5	1.0	1.5	2.0	3.0	5.0	8.0	10	20	40	43
	Gradual accumulation (%)	17	17	19	23	25	30	43	55	63	87	98	100
No.3.	Particle size distribution (μm)	0.3	0.4	0.6	0.8	1.0	2.0	3.0	5.0	8.0	10	20	30
	Gradual accumulation (%)	12	15	20	24	29	44	58	72	85	89	94	100

4.Stone Sludge: (Table 5 lists the chemical characteristics and Toxicity Characteristic Leaching Procedure (TCLP) for Granite stone sludge) There are a lot of stone material industries in the eastern Taiwan. The stone cutting produces large amounts of stone sludge and scrap. According to our estimate, around 1 million tons of sludge and scrap are produced annually. The scrap maintains the same character as granite, and can be reused as a surface for furniture or be broken into coarse pieces. The huge amounts of fine dust and stone sludge cause air pollution, while the deficiency of the landfill site provokes environmental problems. Therefore, the best way to solve the worrisome problems is to recycle the stone sludge.

Table 5. The chemical analysis and Toxicity Characteristic Leaching Procedure (TCLP) for Granite stone sludge.

	Analysis items	Constitution (%)	
Chemical characteristics	L.O.I.	8.5~12.6	
	SiO_2	50~60	
	Al_2O_3	9.7~10.3	
	Fe_2O_3	3.3~4.1	
	CaO	10.3~12.1	
	MgO	3.5~6.9	
	Others	5.1~7.1	
	Total	100	
Toxicity Characteristic Leaching Procedure (TCLP)	Analysis items (mg/L)	Granite stone sludge	EPA regular (mg/L)
	Pb	0.267	5.0
	Zn	0.034	–
	Cr	0.056	5.0
	Cd	0.019	1.0
	Cu	0.003	15.0
	pH	9.7	12.5

Four kinds of inorganic wastes exist (Coal fly ash, paper sludge, dam sediment and stone sludge) and all contain similar mineral components, such as clay and shale, which share the same chemical characteristics and benefit the formation of the lightweight aggregates. The techniques herein were according to base on the suitability of raw materials, for example, cold bonding with cement, sintering, and bloating behavior.

METHOD OF THE EXPERIMENT

Facilities of the experiment:

1.Mixer:

a.The dried inorganic waste is crushed with a bi-wheeled Roller Mixer, then rolled and flattened into powder to obtain a highly uniform material.

b.The different types of inorganic waste powders are then added into the Omuni type mixer, turned up and down and stirred with a stick to mix the raw materials.

2.Pelletizing equipment: (see Fig. 1.)

a.The equipment is pan-shaped, with a diameter of 1m and a pan height of 20cm

b.The pelletizing equipment can be sloped and rotating. Continuous supply of inorganic waste powders to an appropriate site is used to pelletize the powder in pelletizing pan into different sizes, ranging from 10mm to 20mm.

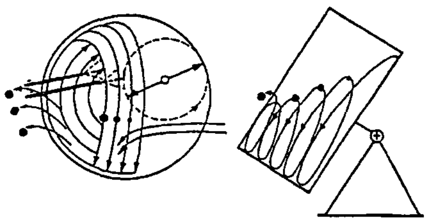


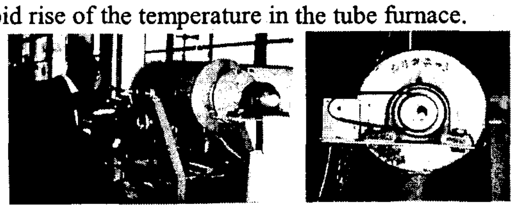
Figure 1. The pelletizing equipment model

3. Burning facility:

a.Oven: electro-thermal type, capacity 50cmx 50cmx 60cm .The oven preheats and sinters the pelletized material. b.Tube furnace: (see Picture 1.)

(1) The Al_2O_3 chinaware tube (diameter 5cm, and length 100cm) lying inside of a furnace tube.
The furnace tube is revolved by motor. The furnace temperature may rise as high as 1350℃.

(2) The furnace tube can be heated and continuously fed raw material. It can be used to imitate a Roll kiln and small-scale experiments can be conducted.
The pelletized bloating materials expanded due to the rapid rise of the temperature in the tube furnace.



Picture 1. The operation condition of tube furnace

4. Compression tester:

ELE Digital Tritest 50 type compression tester with a standard force ring 10 kN, and an operating range from 0 to 1,000kgf.

The test of the physical properties of the lightweight aggregate:

The major physical properties of the lightweight aggregate tested herein are water absorption rate (%), volumetric specific gravity and point loading (kgf).

1.Water absorption rate and volumetric specific gravity: (The Selective Toweling Method as *CNS 488 refers to ASTM C 127 and JIS A1110)

a. The lightweight aggregates are boiled in water for two hours, and then set to cool down to the room temperature.

b. The water is wiped off the particles. Then the particles are weighted **[W]**.

c. The weight of the particles suspended in water is measured; the weight **[S]** is recorded.

d. To dry the particle at 100 ± 0.5°C for four hours and then the weight of the particles is measured and recorded **[D]**.

*CNS: Chinese National Standard.

The formula of water absorption:
WA (water absorption)=(W-D)÷D×100%...①
The formula of volumetric specific gravity:
VSG (volumetric specific gravity)=D÷(W-S). ②

2. The point loading (kgf):

The point loading of the lightweight aggregate serves as the index of the strength of concrete products. Significant variability exists in lightweight aggregate manufacturing procedures and compositions. The compositions of lightweight aggregate are not uniform, so point loading is more important to the lightweight aggregate.

The diameter of the lightweight aggregate is set at 10mm. The single point loading of the aggregate can be obtained directly by utilizing compressive tester testing.

Preparation of lightweight aggregate:

200kg of coal fly ash was tested herein, along with 1,000kg of dam sediment, 50kg of oily ash from the Taipower CORP. and 100kg of Granite stone sludge.

1.Pre-treatment:

a. Dry and grounding: The dam sediment and stone sludge are muddier mud to be oven dried and ground with a running mixer before use.

b. Pelletizing: Pelletizing pan produced an average pellet diameter of 1.5cm~2.0cm.

2. The cold-bonding method: The cold-bonding type lightweight aggregate uses cement and Blast furnace cement as binders. This method uses coals fly ash and paper co-generation ash as the raw material. The experimental procedures involve selecting a raw

material for mixing and then palletizing, followed by hardening through curing, and finally screening. Figure 2 illustrates the process of the cold-bonding method.

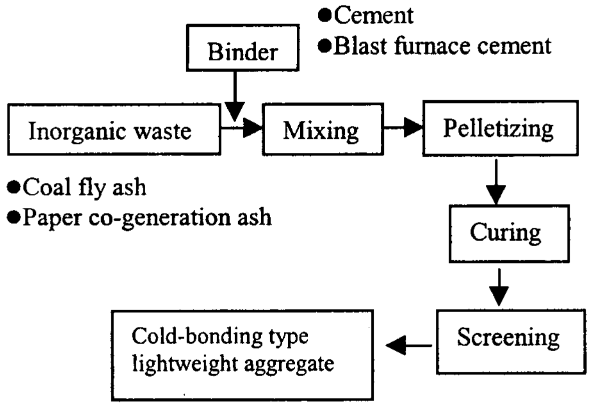


Figure 2. The process of the cold-bonding method

3.The sintering method uses high temperature to sinter and combine the raw material particles to strength the lightweight aggregate. The temperature is maintained at around 1150~1250℃ during the production of the sintering type lightweight aggregate. The sintering uses coal fly ash and paper sludge as raw materials. Figure 3 displays a flow sheet of the sintering method.

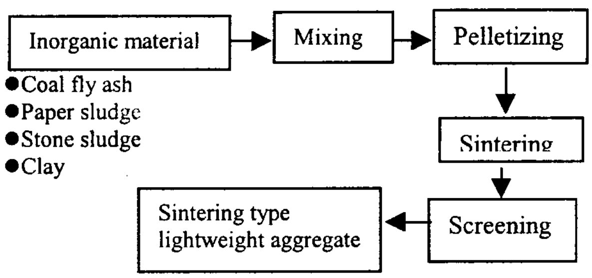


Figure 3. The process of sintering method

4.The bloating method relies upon high temperatures to combine the particles of inorganic waste and bloating to the lightweight aggregate. Appropriate materials such as coal fly ash, dam sediment and stone sludge are selected by our research, which contain Fe_2O_3 and SiO_2 elements. The oxygen will expand during heating. The experimental procedures are as follows:

a. Raw material is first dried and then ground into powder.
b. An aid-bloating agent is added.
c. The OMNI mixer mix sample uniform is used, which takes 5 to 10 minutes.
d The mixing powder is palletized.
e Heating & bloating and screening are conducted. Figure 4 illustrates the flow sheet of the bloating method.

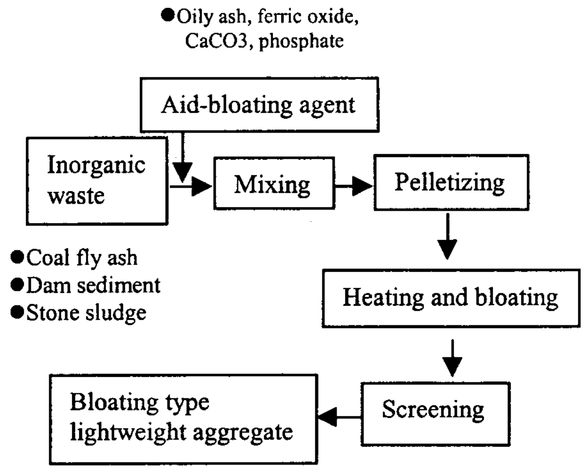


Figure 4. The process of bloating method

Results and Discussion

THE CONDITIONS OF PELLETIZING:

1.The rotation rate (w) of the pelletizing equipment: 49cm/sec～115cm/sec
2.Slope angle (θ) of the pelletizing equipment: 30°～39°
3.Speed of feeding material: 20kg～130kg／hour

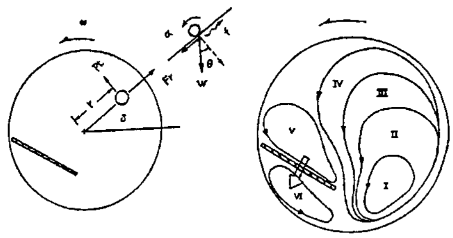


Figure 5. The factor of palletizing

The utilization of the pelletizing equipment obtains the circle granule from inorganic waste. The rotation rates and slope angles of the palletizing effect are compared herein. Figure 6 presents the effects of rotation rate and slope angle.

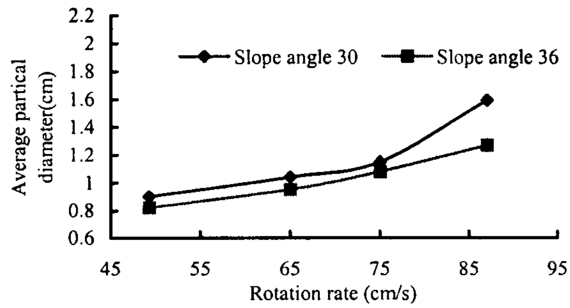


Figure 6. The effects of rotation rate and slope angle

THE PREPARATION OF LIGHTWEIGHT AGGREGATE

The cold bonding type lightweight aggregate

1. The effects of different carbon content and amounts of cement

It is the different grade of coal fly ash, which passing screen 325 mesh and decreasing the carbon contain amount. Table 6 displays the effects on point loading of different levels of carbon content and different amounts of cement.

Table 6. The physical property of lightweight aggregate with different grade of coal fly ash (28 days curing)

Different grade of coal fly ash	Amount of cement (%)	The point loading (kgf)	Water absorption water absorption (%)	Specific gravity (g/cm³)	Carbon contain amount (%)
Pass screen 325 mesh	10	15	23	1.49	5.18
	15	29	20	1.54	
	20	40	18	1.60	
Pass screen 325 mesh	15	25	24	1.49	6.75
	20	37	23	1.50	
Pass screen 150 mesh	20	30	23	1.49	8.20
Raw material	20	32	28	1.37	13.77

Carbon reduces the strength of the cold-bonding type aggregate. The coal fly ash, which passes 325 mesh, can increase the strength by around 20%. The point loading of cold bonding type lightweight aggregate corresponds positively with the amount of added cement, and corresponds negatively with the carbon content of the coal fly ash.

2. The effects of point loading variation by atmospheric and steam curing

20% cement is added to the coal fly ash to palletize it. Meanwhile, the atmospheric curing is conducted at room temperature, while the steam curing is conducted at 60℃. Figure 7 presents the effects of point loading by atmospheric and steam curing.

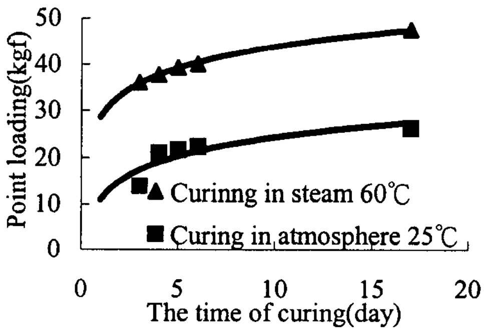


Figure 7. The effects of point loading variation by curing in atmosphere and steam

The cold bonding type lightweight aggregate curing under steam conditions can enhance point loading.

The sintering type lightweight aggregate

1. The effect of the sintering method on stone sludge in dam sediment

This method involves adding 5~20% stone sludge to the dam sediment and raising the heat from 1,125℃ to 1,150℃. Table 7 lists the physical properties of the sintering type lightweight aggregate. The Water absorption rate is the direct ratio for increasing the amount of stone sludge and raising the sintering temperature.

Table 7. The sintering result about adding 5~20% stone sludge in dam sediment. .

Dam sediment / stone sludge	Temperature (℃)	Heating prolong (hr)	Water absorption (%)	Specific gravity
95/5	1125	1	0.83	1.92
	1135	1	1.20	1.80
	1150	1	2.59	1.47
90/10	1125	1	3.1	1.76
	1135	1	4.83	1.51
	1150	1	3.89	1.22
85/15	1125	1	5.21	1.81
	1135	1	9.08	1.53
	1150	1	12.23	0.98
80/20	1125	1	7.27	1.75
	1135	1	11.41	1.52
	1150	1	24.78	0.87

2. The point loading of the sintering type lightweight aggregate

The No.2, No.4 and No.7 heads of the Shi-Men Dam sediment pools serve as the material for the sintering lightweight aggregate. The condition is sintering at 1,150 ℃, with the heating being prolonged for 20 minutes. Table 8 records the average physical properties.

Table 8. The physical properties of sintering lightweight aggregate

Sediment pools (head)	Specific gravity	Water absorption (%)	The point loading (kgf)	The range of diameter
2	2.09	7.32	91.40	1.7~1.9 cm
4	2.08	6.63	81.07	
7	2.04	10.06	140.67	

The water absorption rate decreases with increasing sintering time. The point loading ranges from 81 to 140 kgf, and is suitable for application to supporting the pressure of the building structure.

The bloating type lightweight aggregate

1. The spontaneous bloating material

To make the Shi-Men Dam sediment pool no.13' sediment as expand material by heating at 1,150℃ and heating prolonged for 20 minutes of the bloating type lightweight aggregate. The contrast samples are made from crude shale and imported from Portugal lightweight aggregate products "Leca". Table 9 lists the physical properties of the bloating type lightweight aggregate.

The Specific gravity of the bloating type lightweight aggregate is below 1.0 and its point loading ranges from 20 to 35. The aggregate is thus suitable for application in partition, heating insulation and fireproof materials.

Table 9. The physical properties of the bloating type lightweight aggregate

Type	Specific gravity	Water absorption rate (%)	Point loading (kgf)	Particle diameter range (cm)
Crude shale	1.25	27.76	79.48	1.7~1.9
Leca (Portugal)	0.76	65.08	21.47	
Shi-Men Dam sediment	0.94	14.05	32.20	

2.The non-bloating material: The following compounds have aid expansion effect such as phosphatic compounds, oily ash, Fe_2O_3 and $CaCO_3$ etc.

a. The non-bloating dam sediment adds 2% of phosphatic compounds, and is heated from 1,150℃ to 1,220℃, with the heating be prolonged for 5 minutes for the bloating type lightweight aggregate. The physical properties are as displayed in Fig. 8.

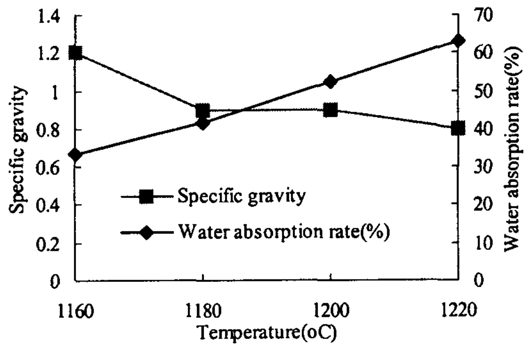


Figure 8. The physical properties of the bloating type lightweight aggregate

b. The non-bloating dam sediment contained additional oily ash 0.5%, Fe_2O_3 0.25% and $CaCO_3$ 0.25%, heating from 1,200 ℃ to 1,280 ℃, with the heating being prolonged by 5 and 10 minutes for the bloating type lightweight aggregate. Figures 9 and 10 present the physical properties.

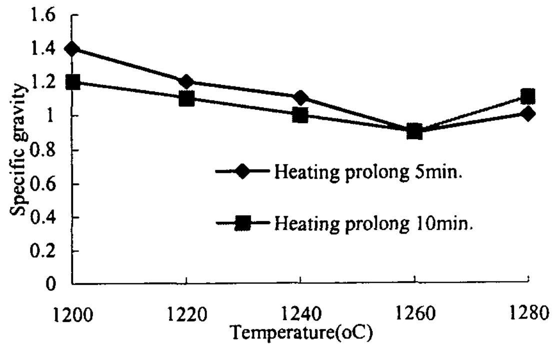


Figure 9. The specific gravity of the lightweight aggregate

The non-bloating dam sediment adds the expanding agent and heating from 1,200℃ to 1,280℃ to make the lightweight aggregate of specific gravity range from 0.7 to 1.0, with a water absorption rate of below 30% and point loading of over 30kgf.

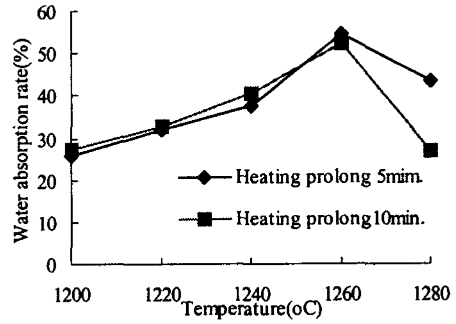


Figure 10. The water absorption of the lightweight aggregate

CONCLUSION

Large public construction projects in Taiwan are increasing the requirements for natural aggregate capacity. Current demand is for one hundred million tons per year. For the economic advancement of society, the design of construction is gradually evolving towards high stratum grade. Further considering Taiwan's location in an earthquake area, lightweight construction of building structures is necessary. Consequently lightweight aggregates are eagerly demanded to substitute for natural aggregate. The demand capacity of lightweight aggregate is estimated at around 30 hundred million tons annually, with a value of 5~10 hundred million NT dollars. Therefore inorganic wastes could be used to make lightweight aggregate and applied to various buildings and structures. This effective use of resources can reduce general industrial wastes by around 13~17%, and now is the critical time for developing the artificial lightweight aggregate technology for its practicability as well as its necessity.

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