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Feasibility Study on Manufacturing Lightweight Aggregates from Water Purification Sludge

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Abstract. This study mainly discussed the feasibility of manufacturing lightweight aggregates from water purification sludge in Taiwan. They were analysed for the physical and chemical composition before the sintering test for lightweight aggregates in a laboratory. Then the physical and mechanical properties of the synthesized aggregates were assessed. The result showed that the chemical composition of sludge in the water purification plants was within the appropriate range for manufacturing lightweight aggregate as proposed in the literature. The sintering test demonstrated that the particle density of aggregates from the ten types of water purification sludge were mostly less than 1.8 g/cm3. In addition, the dry unit weight, the organic impurity, the ignition loss, and other characteristics of synthesized aggregates met the requirement of CNS standards, while its water absorption and crushing strength also fulfilled the general commercial specifications. Therefore, reclamation of water purification sludge for production of lightweight aggregate is indeed feasible.

1. Introduction

Lightweight aggregate (LWA) is a general term for natural or artificial aggregate with a bulk density of less than 1200 kg/m3 [1]. LWA can be used to replace ordinary aggregate to produce lightweight aggregate concrete (LWAC), which has the advantages of light weight, heat insulation, strong fire and seismic resistance [2-4]. As a result, LWA has long been used by many countries as building materials [1,5,6]. In recent years, the development of LWA has focused on industrial waste or municipal solid waste as a raw material to reduce the use of natural resources. A number of studies have been proposed on the production of LWA. For instance, the feasibility of the use of paper sludge, textile sludge, sewage sludge, incineration fly ashes, reaction ashes, and reservoir sediments in manufacturing LWA has been confirmed. In other words, industrial waste or municipal solid waste can be reused as a sustainable resource in the manufacturing process of artificial LWA.

2. Experimental Procedure

In this study, the overall procedure involves granulation, drying, and sintering. Sintering was further divided into a preheating phase and a sintering phase. A series of different conditions (i.e., soaking time at preheating phase and sintering temperature at sintering phase) were planned. Then the sintering test was conducted in a laboratory to analyze the thermal expansion range and the range of attainable particle density for mass production reference. Physical and mechanical properties of the synthesized aggregates were subsequently assessed.

The sludge was thoroughly blended with a controlled amount of water to produce a mix consistency, and was grained by an extrusion pelletizer that was manually chopped into cylinder-shaped pellets as raw pellets. The cylindrical pellets were approximately 10 mm in diameter and 12 mm in length. After sintering, the green pellets were dried in an oven at 105 ±10 ℃ for 24 hours to obtain sufficient particle strength, and it could prevent possible fragmentation from high temperature rupture or steam explosion.

3. Results and Discussion

The physical test of water purification sludge included grain size analysis, soil classification, and specific gravity, in which two samples from the low flow period and the high flow period were used for particle size distribution test. The specific gravity, plasticity index, medium particle size, and composition of water purification sludge from the ten purification plants are shown in Table 1.

Table 1. Physical properties of water purification sludge.

Name of purification plant	Specific gravity	Plasticity Index P.I. (%)	Medium particle size D_{50} (mm)		Composition (% wt.)							
					Gravel		Sand		Silt		Clay	
					＞ 4.75 mm		4.75-0.075 mm		0.075-0.005 mm		＜ 0.005 mm	
			High flow period	Low flow period	High flow period	Low flow period	High flow period	Low flow period	High flow period	Low flow period	High flow period	Low flow period
Hsinsan	2.60	9	0.009	0.002	0	0	9	1	58	25	33	74
Banxin	2.62	10	0.007	0.005	0	0	6	1	52	46	42	53
Pingzhen	2.75	13	0.014	0.003	0	0	2	3	67	30	31	67
Hsinchu	2.69	17	0.006	0.005	0	0	3	2	49	53	48	55
Fengyuan	2.60	13	0.010	0.009	0	0	12	3	56	68	32	29
Linnei	2.75	11	0.005	0.004	0	0	1	1	38	47	61	52
Nanhua	2.63	13	0.010	0.004	0	0	1	4	65	38	34	58
Pingding	2.7	27	0.008	0.007	0	0	4	2	78	68	18	30
Kaotan	2.64	26	0.007	0.003	0	0	5	1	55	31	40	68
Chengcing Lake	2.63	14	0.011	0.008	0	0	8	3	75	58	17	39

The chemical composition of the water purification sludge from the ten purification plants is shown in Table 2. It can be seen that the water purification sludge from the ten purification plants satisfied Riley's recommended requirements [7]. In other words, the chemical composition of sludge in the ten water purification plants was within the appropriate range as proposed in the literature. Especially, the mineral composition of the clean water sludge sample shows that all samples contained quartz and clay mineral compounds such as chlorite, illite, feldspar and others. The result showed two characteristics that the mineral compositions of all water purification sludge samples conformed with striking similarity and water purification sludge indeed show manufacturing potential of LWA.

Table 2. Chemical composition ratio of water purification sludge.

Chemical composition	Name of purification plant										C.M. Riley Recommended Range
	Hsinsan	Banxin	Pingzhen	Hsinchu	Fengyuan	Linnei	Nanhua	Pingding	Kaotan	Chengcing Lake	

SiO_2 (%)	64.3	63.6	63.8	64	62.3	66.9	62.3	54.8	65.6	63.7	53-79
Al_2O_3 (%)	21.2	22.2	20.6	23	22	20.6	21.4	23	22.4	19.6	12-26
Fluxing (%)	14.5	14.1	15.5	12.9	15.6	12.4	16.3	22.1	12.0	16.4	8-24
Total (%)	100	100	100	100	100	100	100	100	100	100	—

Note: Fluxing=Fe_2O_3+CaO+MgO+K_2O+Na_2O

Table 3. Physical properties of aggregates.

Name of purification plant	Preheating phase		Sintering phase		Particle density (g/cm^3)	Water absorption (%)	Ignition loss (%)	Bloating index (%)
	Preheating temperature (℃)	Soaking time (min.)	Sintering temperature (℃)	Soaking time (min.)				
Shinshan	500	0	1275	10	1.29	11.3	14.5	104.4
		7.5			1.33	10.6	14.0	101.4
		15			1.40	9.6	14.7	96.5
Banxin	500	0	1275	10	1.29	11.3	15.2	102.9
		7.5			1.39	7.3	15.0	95.7
		15			1.65	3.7	15.0	80.5
Pingzhen	500	0	1275	10	1.50	5.0	14.3	106.5
		7.5			1.57	4.5	14.5	102.0
		15			1.89	1.9	14.6	84.5
Hsinchu	500	0	1250	10	0.65	8.0	10.1	224.9
		7.5			1.74	1.7	10.7	83.8
		15			1.88	0.6	10.6	77.5
Fengyuan	500	0	1150	10	1.31	19.0	14.6	110.7
		7.5			1.43	15.0	15.2	101.4
		15			1.52	11.0	14.5	95.4
Linnei	500	0	1200	10	0.78	1.2	8.4	162.2
		7.5			1.46	1.0	8.2	86.2
		15			2.38	0.3	7.9	53.0
Nanhua	500	0	1275	10	1.26	7.4	15.1	104.0
		7.5			1.29	4.9	15.3	101.6
		15			1.58	2.7	15.1	82.8
Pingding	500	0	1200	10	0.74	3.7	7.5	228.1
		7.5			1.67	0.9	7.7	100.6
		15			2.05	0.1	7.1	82.0
Kaotan	500	0	1200	10	0.75	4.8	6.5	223.4
		7.5			1.28	1.2	6.1	130.5
		15			2.03	0.3	6.6	82.1
Chengcing Lake	500	0	1200	10	0.73	6.6	6.3	181.8
		7.5			0.79	4.2	6.8	166.2
		15			1.97	0.7	6.4	66.9

Therefore, the samples of water purification sludge should be a suitable expanded material that can develop gases at high temperature. Moreover, they can produce a highly viscous liquid phase at the temperature that could entrap the gases. In short, the specific gravity of sludge was between 2.60 and 2.75, and all of the sediments of silt or clay were suitable as raw materials for the manufacture of artificial LWA.

Name of purification plant	Soaking time at preheating phase/Bloating index		
	0 min.	7.5 min.	15 min.

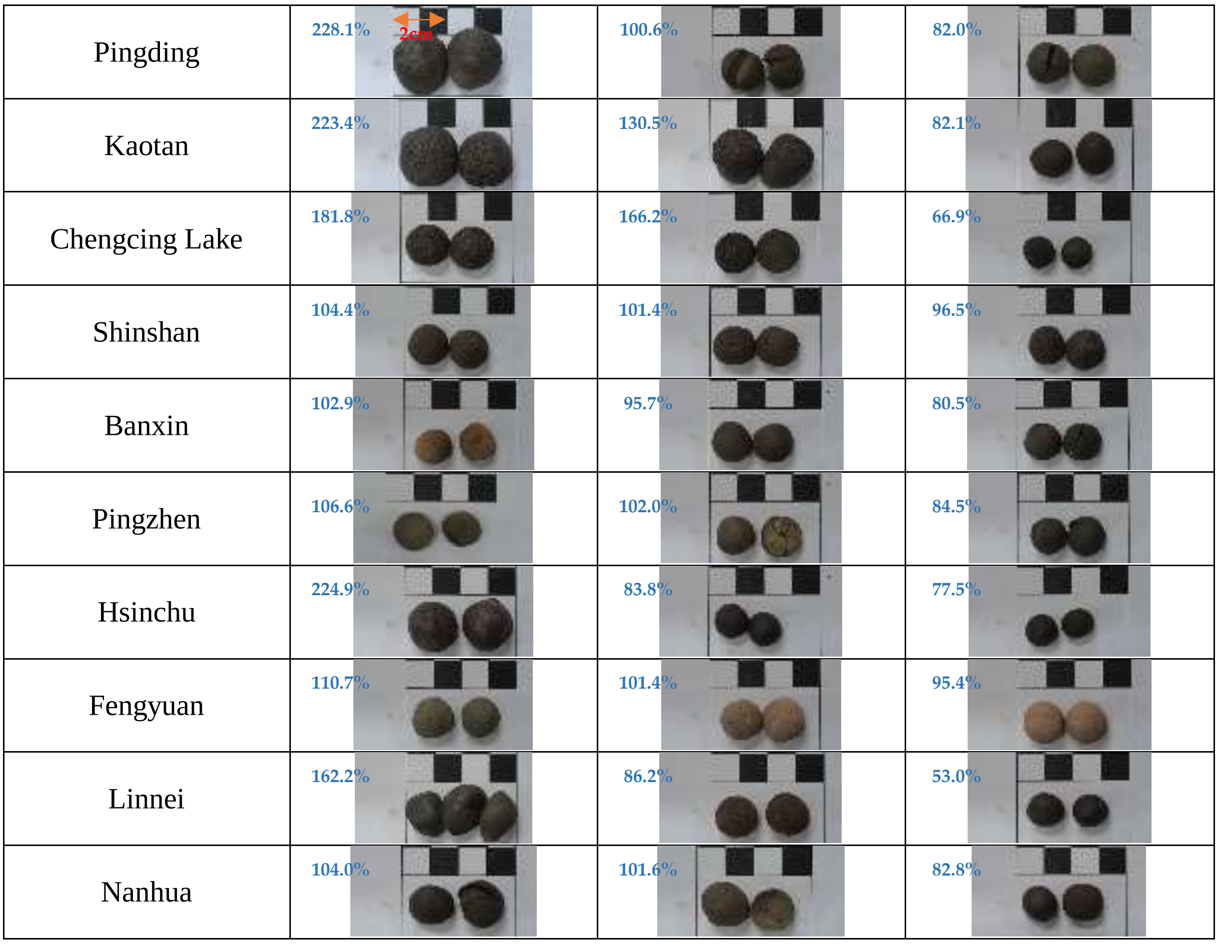

Figure 1. Bloating index of synthesized aggregates versus soaking time at preheating phase.

Taking into account previous findings, the preheating temperature was set at 500 ℃ and the soaking times were 0, 7.5, and 15 minutes, respectively. On the other hand, based on the preliminary trial results, the sintering temperature was the optimal temperature in each group and the soaking time was fixed at 10 minutes. The sintering conditions for water purification sludge of the ten purification plants are shown in Table 3. In addition, the particle density, water absorption, ignition loss, and bloating index of the synthesized aggregates are also shown in Table 3.

The particle density of the synthesized aggregates ranged from 0.65 to 2.38 g/cm3, most of which was less than 1.8 g/cm3. It also illustrated that the soaking time at preheating phase could affect the particle density of aggregate. For any water purification sludge from the ten purification plants, a longer soaking time would result in aggregates of a higher particle density.

As can be seen in Table 3, the 24-hour water absorption values of the synthesized aggregates ranged from 0.1% to 19%, most of which was less than 8%. It demonstrated contrastive effect of lower absorption and higher particle density with increased soaking time. For structural concrete applications, the water absorption of LWA is usually less than 20%. The results indicate that the synthesized LWA in this study meet with regulations.

Table 3 shows that for any water purification sludge from the ten purification plants, the soaking time at preheating phase did not significantly affect the ignition loss of aggregate. On the whole, a higher sintering temperature (1275 ℃) would result in aggregates of a higher ignition loss (> 14%). With exception of 1150 ℃, a lower sintering temperature (1200 ℃) would result in aggregates of a lower ignition loss (between about 6.4% and 8.2%). The results demonstrated a positive correlation between sintering temperature and ignition loss that higher sintering temperature increased the loss on ignition.

From Table 3, it can be seen, a longer soaking time would result in aggregates of a lower bloating index, even a petty volume contraction. Overall, there was a clear inverse relationship between bloating index and particle density/soaking time (see Table 3 and Figure. 1).

4. Conclusions

Based on the above results and discussion, the following conclusions can be drawn:

(1) The specific gravity of sludge was between 2.60 and 2.75, and all of the sediments of silt or clay were suitable as raw materials for the manufacture of lightweight aggregate.

(2) The chemical composition of sludge in the ten water purification plants was within the appropriate range as proposed in the literature. The sintering test demonstrated that the particle density of aggregates from the ten types of water purification sludge were mostly less than 1.8 g/cm^3.

(3) The dry unit weight, the organic impurity, the ignition loss, and other characteristics of synthesized aggregates met the requirement of Chinese National Standards, while its water absorption and crushing strength also fulfilled the general commercial specifications. Therefore, reclamation of water purification sludge for production of lightweight aggregate is indeed feasible.

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