The 2017 World Congress on
Advances in Structural Engineering and Mechanics (ASEM17)
28 August - 1 September, 2017, Ilsan(Seoul), Korea

The Study on the Manufacturing of Cold-bonded Lightweight Aggregate from Stone Sludge

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ABSTRACT

This research is mainly focused on manufacturing lightweight aggregate from waste sludge by cold-bonded method. There are four kinds of bonding materials were adopted such as silicates (cements), polyphosphate, alkali-activated fly ash with alkaline solution, and alkali-activated slag with alkaline solution. The test results indicate that the polyphosphate materials and water has a fast chemical reaction, which causes a difficult pelleting process. When marble sludge was mixed with 30% cement or alkali-activated materials (30% of slag added 5% of alkaline solution), and cold-bonded lightweight aggregates were produced successfully. The aggregate particle density is between 1,635~1,782 kg/m^3; their absorption capacity is between 17.7~24.8%, and the aggregate crushing value is between 211~700 N.

Keywords: Lightweight aggregate, Cold-bonded, Stone sludge, Slag, Alkali-activated

1. INTRODUCTION

Stone products will require mechanical processing, such as cutting, sawing, drilling, grinding and trimming. In the manufacturing process will produce a lot of mud, gravel, steel powder, lime and other chemical composition. This mixed compound is known as “stone waste sludge” (SWS). The classification of stone waste sludge is in accordance with the original stone types, such as the marble waste sludge, granite waste sludge, and serpentine waste sludge, etc. According to the statistics from Taiwan Stone Industry Research and Development Center, there are about 810,000 tones stone waste sludge was generated each year in Taiwan. Traditionally, the landfill method most commonly used to dispose of stone waste sludge due to the method is more convenient. However, this method will need a lot of land and contrary to the new

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concept of environmental protection. How to recycling the stone waste sludge is a topic which is worth discussing. The most successful case is marble waste sludge reuse as cement raw materials (Hüseyin 2010 and Ali A.Aliabdo 2014). Marble's minerals are calcite, so the marble waste sludge is also rich in calcium carbonate. When the waste sludge replaced part of marble material, it still succeeded in making cement. However, there are three reasons reduced the marble waste sludge as raw materials for cement. First, Cement yield in Taiwan was reducing. Second, using marble waste sludge in manufacturing of cement affected its quality. Last, low-carbon policy is pursuing. Therefore, it is necessary to study a suit reuse method for marble waste sludge.

Many literatures found that the powdered clay suitable as raw materials for producing lightweight aggregates used in concrete. Lightweight aggregate is one of several materials used to decrease the unit weight of concrete, thereby reducing the structural load and the cost of the building. The use of lightweight aggregate is costly, but sometimes necessary in construction. Lightweight aggregates is required the unit weight of less than 1040 kg/m^3 or the value less than 2000 kg/m^3 in particle density (Short 1963). It possesses many characteristics such as low density, low strength, low weight, high water absorption, porosity, and rough surface etc. Lightweight aggregates can be fall into two broad categories: natural type and artificial type. Natural aggregates were mined from the area of volcanic activity, including pumice, vermiculite, volcanic ash, tuff, and so on. Natural aggregates have not only little production volume but also varies properties. The artificial lightweight aggregate has many types including expansion clay, expanded shale, perlite, vermiculite, expanded furnace slag, and other lightweight aggregates sintered from the waste sledges. Its particle density can be controlled between 0.1~2.0 g/cm^3. The artificial lightweight aggregate is more popular than natural lightweight aggregate.

The production methods of the artificial lightweight aggregate can be divided into: sintered and cold-bonded. To manufacture the sintered lightweight aggregates, the chemical composition of raw materials is subject to certain conditions. The pellets have to sinter at high temperature 1100 to 1200°C, let raw materials produce some gases. And the gases were kept inside of the pellets until the sintered pellets cooled down. And then the pellets became lightweight aggregate with porous structures. Professor Huang (2013) used the granite waste sludge as raw materials and successfully produced the lightweight aggregate by high temperature sintering process. Marble stone sludge with high calcium oxide and low silica chemical composition makes them unsuitable as sintered lightweight aggregate materials. On the other hand, the sintered method has to demand higher energy. That is not meet the trend of energy saving.

Cold-bonded lightweight is a porous spherical particle made from the powdery materials and binder materials. For the production technique of cold-bonded lightweight aggregate, the production equipment is simpler and less energy consumption. Many scholars show that the using Pozzolanic materials successfully produce lightweight aggregates by cold-bonded technology. Mehmet Gesoglu (2007) made cold-bonded lightweight aggregate from fly ash with water glass (sodium silicate). The density of lightweight aggregate vary between 1.7~1.8 g/cm^3, 24 hours water absorption vary between 5~35%, 28-day compressive strength vary between 50~900 N. Mehmet Gesoglu and Erhan Guneyisi (2012) used fly ash and slag in manufacturing lightweight aggregate, and Portland cement is as the binder materials. The density of lightweight aggregate vary between 1.6~2.2 g/cm^3, 24 hours water absorption vary between 5 ~20%, 28-day compressive strength vary between 65~1070 N. Francesco Colangelo (2013) research show that cement kiln dust and slag can produce cold-bonded lightweight aggregates. With 28 days of curing, the particle density of aggregates is between 1700~2000 kg/m^3 and water absorption are between 2~24%.

Stone sludge can be successfully reused for sintered lightweight aggregates, but it needs the support of higher energy. It does not meet the concepts of environmental sustainability and carbon reduction. And marble stone sludge composition is not suitable as the raw materials for sintered lightweight aggregate. This research aims to use marble stone sludge as raw material for producing lightweight aggregates by cold-bonded method.

2. PROPOSED FAILURE SURFACE

IF the marble stone waste cannot make effective reuse will cause environmental problems. This study reused marble stone sludge in manufacturing of lightweight aggregate by cold-bonded method. There are four kinds of binder materials were adopted. The hydration of the binder materials will enhance the strength of marble stone sludge after mixing binder materials and marble waste sludge. From test and analysis on engineering properties of lightweight aggregate, effects of binder on the properties of cold-bonded lightweight aggregate were studied. And then it could assesse the feasibility of marble waste sludge reused in cold-bonded lightweight aggregate. The development of this technology helps to the waste resource and energy saving.

3. Research program

3.1 Test materials

Marble waste sludge’s specific gravity is about between 2.68~ 2.75 and moisture content is between 30%~50%. Its particle size distribution range is between 0.5~ 300μm, LOI. 42.2%. Silicate materials adopted type I Portland cement with 3.15 in specific gravity and 3620 cm^2/g in fineness. Principal component contains calcium oxide (CaO) and silicon dioxide (SiO_2), the contents of 63.56% and 19.08% respectively. Its loss on ignition is 1.38%. The properties meet the CNS 61 Portland cement standard. Phosphate is a kind of powder material with high contents of magnesium, phosphates and other ingredients combination. Its specific gravity is 2.64, and with a light weight, high strength, acid (pH3~pH11), and within 30 minutes setting and other characteristics. The specific gravity of fly ash used in this research is 2.2. And its fineness is 2899 cm^2/g and the loss on ignition is 5.78%. It met the specifications of ASTM C618. And according to this specification, the calcium oxide content of less than 10% belongs to the F-class fly ash. The Furnace slag powder with 2.86 in specific gravity and 6000 cm^2/g in fineness modulus was used. The main chemical compositions are calcium oxide (CaO) and silicon dioxide (SiO_2) content of

40.34% and 32.2% respectively. The Sodium hydroxide solution (chemical formula NaOH) with pH value of 14 was also used. The specific gravity of NaOH solution varied between 1.01~1.53 due to the concentration and temperature. NaOH concentration and temperature influence on its density, the specific gravity of NaOH solution changes from 1.01 to 1.53.

3.2 Preparation of LWA

All the raw materials were first dried at 110 ℃. The slag and sludge were crushed to small pieces and then grinded respectively in ball mill for 2 h to attain more than 90% fine powder (passing 200 mesh sifter). The pellets were hand-crafted with a binder/sludge mixture of 30/70% and approximately 30% water. The Size of pellets changed from 12mm to 15 mm in diameter, as shown in Fig. 1. Then the green pellets were curing at 24 ℃ and RH 75% for 24 h. It shall be noted that the polyphosphate materials and water has a fast chemical reaction, which causes a difficult pelleting process.

Fig. 1 The pellets of cold-bonded lightweight aggregate

3.3 Experimental variables and mixture design

This study uses four different binder materials, including silicates (cement), phosphates, fly ash, and slag powder. Because the hydration of fly ash and slag powder are very slow, it needs to add alkali to speed up the hydration. All of the mix designs were shown in Table 1. The specimen number consisted of six codes. The number following “M” represents water to binder ratio; the number following “R” represents binder replaced rate; the number following “N” represents the added rate of sodium hydroxide. For example, M30FR05N05: the specimen with a water-binder ratio 0.30, the replacement rate of fly ash 5%, and add sodium hydroxide 5%.

3.4 Test method

This study conducted specific gravity, water absorption and particle strength test for cold-bonded lightweight aggregates. Test method for water absorption and specific gravity are in accordance with the reference to the United States ASTM C127 specification. The strength of each single pellet was measured by uniaxial compression between two parallel rigid platens. It was referred to the British Standard BS 812: Part 110:1990 granular spot value (Aggregate Crushing Value). The average particle strength of aggregates was obtained from 15 times test.

Fig. 1 Mixtures for cold-bonded lightweight aggregate

No.	Binder types	Sludge(g)	Binder(g)	Water(g)	W/B ratios	NaOH(%)
M20PR30N00	Portland cement (Silicates)	210	90	81.0	0.2	0
M30PR30N00		210	90	90.0	0.3	
M20GR30N00	Phosphates	210	90	81.0	0.2	0
M20GR40N00		180	120	78.0	0.2	
M30FR05N00	Fly ash	285	15	90.0	0.3	0
M30FR30N05		210	90	90.0	0.3	5
M30FR30N10		210	90	90.0	0.3	10
M30SR30N00	Slag powder	210	90	90.0	0.3	0
M30SR30N05		210	90	90.0	0.3	5
M30SR30N10		210	90	90.0	0.3	10

4. Test results and discussion

4.1 Fly ash as a binder material for cold-bonded lightweight aggregate

When Fly ash as binder materials added alkaline agent NaOH for cold-bonded lightweight aggregate, it can granulate into a pellet but was quickly decomposes in water. Waste sludge is not bonded to each other, unable to generate enough strength. Fly ash with NaOH as a binder material for cold-bonded lightweight aggregate was failed.

4.2 Effects of binder types on particle density of aggregate

Effects of Binder types on particle density of aggregate are shown as Fig. 2. The diagram shows that the density value of cold-bonded lightweight aggregate made from alkali-activated slag with 5% NaOH is 1635 kg/m^3. When NaOH concentration increased to 10%, aggregate’s density is increased to 1677 kg/m^3. The particle density of cold-bonded lightweight aggregate with 0.2 and 0.3 water-binder ratio of cement binder are 1717 kg/m^3 and 1782 kg/m^3, respectively. The particle density of lightweight aggregate with phosphate binder is 1657 kg/m^3. The particle density values of all of aggregates are varied between 1635~1782 kg/m^3, it is consistent with lightweight aggregate standard which its particle density must be below 2000 kg/m^3.

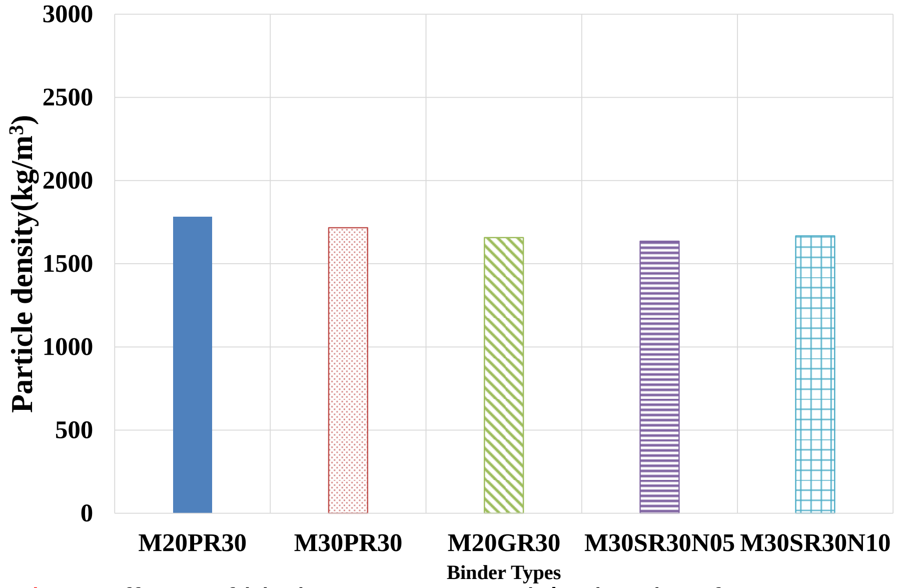

Fig. 2 Effects of binder types on particle density of aggregate

4.3 Effects of binder types on water absorption of aggregate

Effects of Binder types on water absorption of aggregate are shown as Fig. 3. Test results show that the cement binder aggregate's water absorption is less than 20%; phosphate and two sets of alkali-activated slag powder lightweight aggregates' water absorption are greater than 20%. Therefore, the cold-bonded lightweight aggregate made from silicate materials (cement) and waste marble sludge could possess lower water absorption and fewer pores.

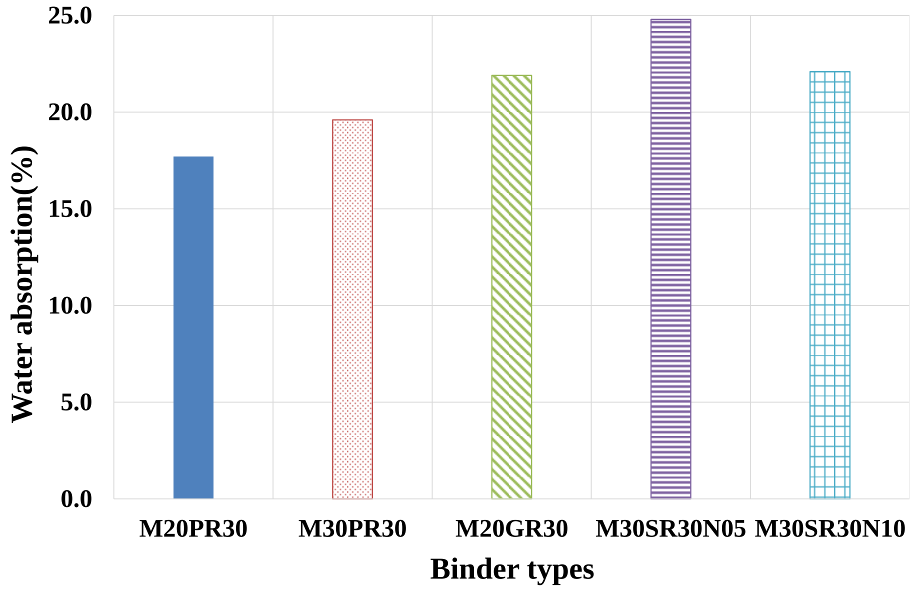

Fig. 3 Effects of binder types on water absorption of aggregate

4.4 Effects of binder types on particle strength of aggregate

Effects of binder types on particle strength of aggregate are shown as Fig. 4. The particle strength tests were carried out at 28 days after curing under the binder materials to replace stone waste sludge as 30%. The average particle strength of aggregate with 0.2 and 0.3 water-binder ratios are 650 N and 700 N, respectively. The particle strength values of aggregate are 404 N and 615 N for two alkali-activated slag powder groups; the average particle strength of aggregate is 211 N for phosphate group. Test results showed that phosphate as a binding material is unfavorable to the strength property of cold-bonded lightweight aggregate.

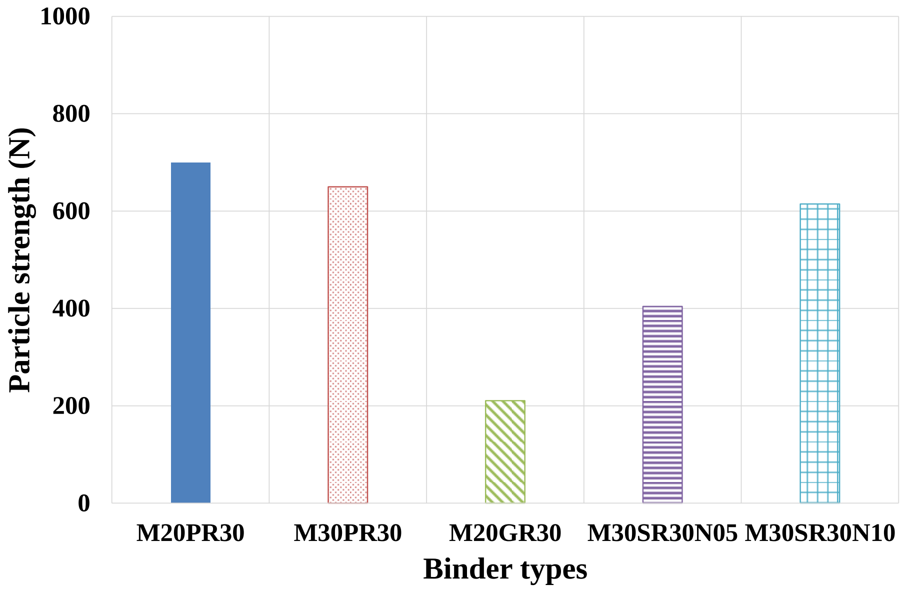

Fig. 4 Effects of binder types on particle strength of aggregate

5. Conclusion

1. Fly ash mixing sodium hydroxide has no cementation. They are not suitable as a cementing material for cold-bonded lightweight aggregate. The polyphosphate materials and water has a fast chemical reaction, which causes a difficult pelleting process
2. Three kinds of binder material such as silicates (cements), polyphosphate, alkali-activated fly ash with alkaline solution, and alkali-activated slag with alkaline solution mixed marble waste sludge can be successfully produced lightweight aggregates. Their particle density values are 1782 kg/m^3, 1657 kg/m^3, 1635 kg/m^3, respectively. Test results show that the binder material type is affected the particle density of cold-bonded lightweight aggregate. The particle density values of all of aggregates are varied between 1635~1782 kg/m^3, it is consistent with lightweight aggregate standard which its particle density must be below 2000 kg/m^3.

3. Under the fixed amount of binder materials and stone sludge, silicate (cement) group aggregates' 24 hours water absorption is 17.7%; phosphate group 21.9%, group of alkali-activated slag is as high as 24.8%. Stone waste sludge mixed with cement cold-bonded to lightweight aggregates, its water absorption performance is the best.
4. On particle strength test results, cement groups have the highest strength values, followed by the alkali-activated slag groups, phosphates group is the lowest. It shows that phosphate power as a binding material is unfavorable to the strength property of cold-bonded lightweight aggregate.
5. In this study, the marble waste sludge as raw material can be successfully produced lightweight aggregates by cold-bonded method. The products possess well engineering properties and can be reused in concrete. it is worthy to note that this technology could help to the waste resource and energy saving.

Acknowledgement

This research is supported by Ministry of Science and Technology, Taiwan, R.O.C. under Grant no. MOST 104- 101-2221-E-122-001.

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