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Production of Artificial Aggregate Using MSWI Bottom Ash Fines (0-2 mm) Applying The Cold Bonding Pelletizing Technique

Tang, P., Florea, M.V.A., Brouwers, H.J.H.
Department of the Built Environment, Eindhoven University of Technology, Eindhoven, 5612AP, the Netherlands
E-mail address: p.tang@tue.nl

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Abstract

Municipal solid waste incineration (MSWI) fine bottom ash (0-2 mm, BAF) is a waste material which has the potential to be used as building material. However, its potential risks on the environment and poor physical properties hinder its application on a large scale. In this study, the BAF is used as raw material for producing artificial lightweight aggregates by applying the cold bonded pelletizing technique. The properties of these aggregates are studied (such as pellet strength, crushing resistance, water absorption, density, etc.) and compared with other artificial aggregates produced from powders. The results show that the aggregates produced in this study have comparable or even better properties than others'. Moreover, the leaching properties of these aggregates are evaluated. The leaching of the sulphate, copper and antimony of the produced artificial aggregates is well under the limit value for the non-shaped materials according to the Dutch legislation. The produced artificial aggregates are used in concrete as natural aggregate replacement, and the properties of the concrete are tested and better concrete strength is obtained compared with others due to the higher crushing resistance of the produced artificial aggregates. The obtained results in this study show that the application of BAF for producing artificial aggregates is a beneficial way of recycling BAF and the natural properties of the BAF turns to have positive influence on the artificial aggregates properties.

1 Introduction

The cold bonded pelletizing technique is successfully used to recycle waste powders for producing artificial aggregate [1,2]. The produced aggregate can be used as lightweight aggregate in concrete and its rounded particle shape benefits the flowability of fresh concrete [3,4]. Municipal solid waste incineration (MSWI) fine bottom ash (0-2 mm) (BAF) has the potential to be used as sand substitute in mortar or concrete [5–8]. However, treatments are needed to improve its poor physical and chemical properties which may lead to damaging the mortar and concrete during application [9–12]. The research on the production of artificial aggregate using waste powders through the cold bonding technique proposes a positive view on the investigation of recycling BAF in the same way, which is rarely studied. In this research, the cold bonded pelletizing technique is used to produce an artificial aggregate using BAF. The properties (such as density, crush resistance, water absorption, etc.) of the artificial aggregate produced are tested, and its leaching properties are measured and compared with the legislation.

2 Methods and materials

The MSWI bottom ash used is collected from a waste-to-energy plant in Moerdijk (the Netherlands) which has an annual processing capacity of one million tonnes. The fine wet bottom ash fraction (0-2 mm) is selected by sieving for the investigation in this study. The others waste powder materials chosen in this research are combustion fly ash (VL), paper sludge ash (PK) and washing aggregate sludge (MZ) from the gravel washing factory. The binder applied is Ordinary Portland Cement (OPC) CEM I 42.5 N.

The chemical compositions of the used materials are determined by X-ray fluorescence (XRF). Laser diffraction (Mastersizer 2000 Malvern) is used to determine the particle size distributions (PSDs) of the powder materials, and the PSD of the particle aggregates is measured following EN 933-2 [13]. The specific densities are measured by helium pycnometer (AccuPyc II 1340). The disc pelletizer used has a diameter of 100 cm and collar height of 15 cm. The optimized speed and angle of the pan are fixed at 15 rpm and 45° during the pelletizing process, respectively. The raw materials are mixed in a concrete mixer and then the certain amount of material is fed to the disc; the water is sprayed during the first several minutes for the generation of new nuclei. Then the disc is continuously run for the generation and compaction of granulates. The next batch of material is added to the disc when the first cycle is finished, then granulates generated during the first cycle will run out of the pan automatically. By following this procedure, the process is continuously running to produce aggregate. The produced aggregate is cured in sealed bucket; batches of aggregate is collected for testing after 1, 3, 7 and

28 days, respectively. The loose bulk density of the aggregate is determined following EN 1097-3 [14], and the water absorption of the aggregate is measured following EN 1097-6 [15]. The crush resistance of the aggregate is evaluated following EN 13055-1 (Annex A, procedure 1) [16]. The column leaching tests according to Dutch standard NEN 7383 (2004) [17] were performed on the artificial aggregate. The leaching values of studied elements are compared with the limit value according to the Dutch legislation [18].

3 Results and discussions

Table 1 shows the chemical compositions of the raw materials used for pelletization. It can be seen that BAF, VL and MZ contain quite high amounts of SiO_2, while PK has relatively high amount of CaO and Cl. BAF and MZ have similar specific densities as natural aggregate (2.65 g/cm^3), and PK has a slightly higher specific density while VL has a lower density.

Table 1. The chemical compositions and specific density of the raw materials

Compositions [% wt.]	CEM I 42.5 N	BAF	PK	VL	MZ
CaO	67.85	18.58	54.94	6.18	1.46
SiO_2	14.85	39.13	13.64	45.20	73.31
Al_2O_3	3.62	7.60	8.64	27.49	11.29
Fe_2O_3	3.33	12.93	0.99	6.63	6.00
K_2O	0.82	1.09	0.46	2.17	1.85
Na_2O	-	1.02	-	0.96	0.61
MgO	1.57	1.93	2.09	1.36	0.89
CuO	0.02	0.38	0.07	0.02	0.00
ZnO	0.07	0.66	0.08	0.05	0.01
Cl	0.11	0.29	2.24	-	0.00
SO_3	4.46	4.33	0.99	1.70	0.16
P_2O_5	0.39	0.86	0.30	0.78	0.07
TiO_2	0.30	1.07	0.74	1.50	0.44
Others	2.59	10.15	14.82	5.96	3.92
Specific density [g.cm^{-3}]	3.10	2.69	2.71	2.32	2.68

Fig.1 shows that the raw powder materials have a similar particle size distribution; VL has a coarser particle size than VL and MZ. The artificial aggregate produced has a particle size mainly between 4-8 mm. The size of the artificial aggregate can be controlled by changing the addition of the raw materials, spraying of water and running duration. A relatively higher initial water content, longer running duration together with water additions benefit leads to a higher amount of bigger particles. Also, the area of adding water at different stages influences the growth speed of pellets and their particle size.

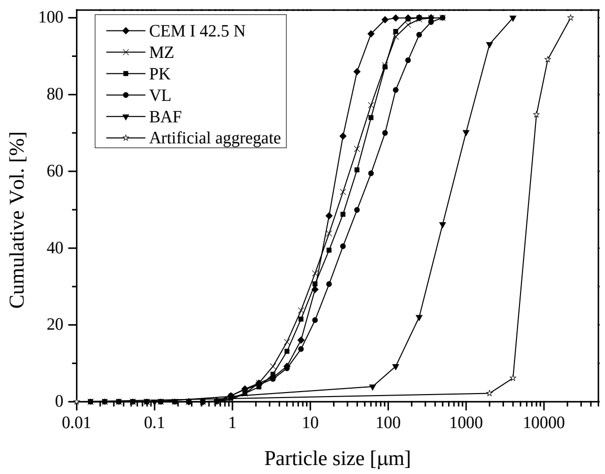

Figure 1. The particle size distribution (PSD) of raw materials and the produced artificial aggregate

Fig. 2 shows that the specific density of the produced aggregate is around 2.5 g/cm^3, which is slightly lower than that of natural quartz aggregate (2.65 g/cm^3). It is known that the specific density of the artificial aggregate is related to the density of the raw materials used [1]. The densities of the fractions are very similar at the same curing age, and there is a small decrease of the densities when the curing time is increasing. The loose bulk density of the artificial aggregate is increasing with curing time and it is below 1200 kg/m^3, which is the upper limit value for lightweight aggregate according to EN 13055-1 [16]. Hence, the artificial aggregate produced using BAF is categorized as lightweight aggregate. The increase of loose bulk density indicates the decrease of aggregate porosity due to the cement hydration.

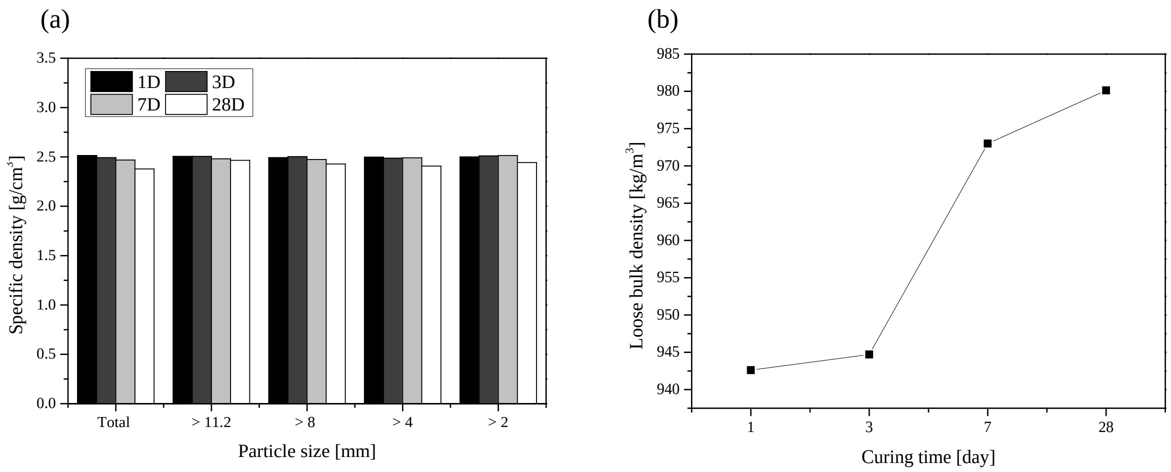

Figure 2. The density of the artificial aggregate after different curing days

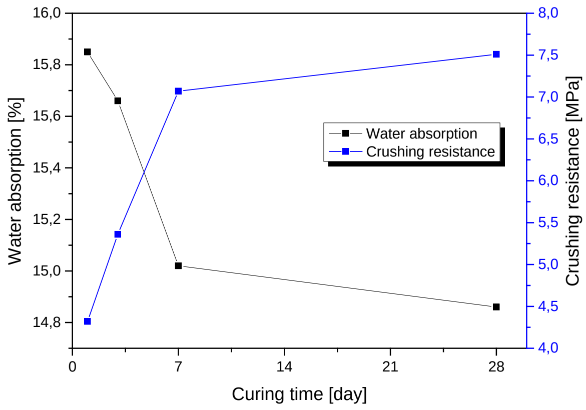

Figure 3. The water absorption and crushing resistance of the produced artificial aggregates after different curing times

Fig. 3 shows the water absorption and crushing resistance of the artificial aggregate fraction 4-16 mm. It can be seen that the water absorption of the aggregate fraction is decreasing with the curing age, while the crushing resistance has an increasing trend with time. Due to the cement hydration, the hydrates fill in the pores inside the pellet and bind the matrix together; in this way the porosity of the pellet is decreased and their strength is increased. The crushing resistance of aggregate increased dramatically at the firstly 7 days, after that the increase is slow. The 7-day crush resistance is around 94% of the corresponding 28-day strength. This may due to the slow pozzolanic reaction of the fly ash. The aggregate produced in this study has a smaller water absorption and higher crushing resistance than the aggregate produced by only powder materials in others studies [19,20].

Fig. 4 shows that the crushing resistance and loose bulk density of the artificial aggregate have a linear relationship with water absorption. The water absorption of the aggregate reflects its porosity, which is influenced by the cement hydration degree, compaction of ingredients in the pellet, etc. When a higher amount of binder is added, more hydration by-products will be generated to fill in the voids in the pellet; this will decrease the porosity of the pellet and then increase the pellet strength. A good compaction of ingredients in the pellets can provide a dense microstructure, which means less voids in the pellet. Therefore, to have a higher crushing resistance of artificial aggregate, increasing binder amount or a better compaction of ingredients during the pelletizing process would be the proper methods. However, in these ways the bulk density of the aggregate may increase. Hence, the properties of the artificial aggregate with BAF can be adjusted according to its application purpose.

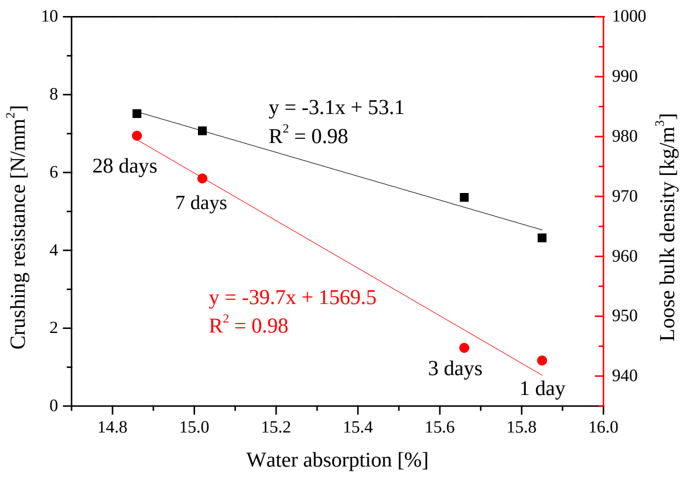

Figure 4. The relation between water absorption, crushing resistance, and loose bulk density of the artificial aggregate

Table 2 shows the leaching properties of BAF and the artificial aggregate. It can be seen that the leaching of Sb, Cu, chloride and sulphate of BAF exceed the limit value according to legislation [18], while the leaching of these components in artificial aggregate is well under the limit value, except Mo and chloride. The leaching of chloride is rather higher compared with other components; this is partially attributed to the higher amount of chloride in PK used in this study. The leaching of Mo is influenced by pH [10], which is quite higher during the cement hydration. Hence, to decrease the leaching of this artificial aggregate, less amount of BAF and other type of PK could be used.

Table 2 Leaching values on BAF, artificial aggregate and the leaching limit value for non-shaped materials in legislation [18]

	Limit value [18]	BAF	Aggregate
Sb	0.16	0.47	0.091
Mo	1	0.68	1.8
Cu	0.9	1.1	0.77
Chloride	616	950	2400
Sulphate	1730	11000	230

4 Conclusions

- The cold bonding pelletizing technique is applied to recycle MSWI bottom ash fines (0-2 mm) together with other industrial waste powders (paper sludge ash, washing aggregate slurry and coal fly ash).
- A type of artificial lightweight aggregate is produced, the bulk density of which is around 980 kg/m^3 and its specific density is around 2.5 g/cm^3.
- The produced artificial aggregate has a lower water absorption and higher crushing resistance compared with the aggregate produced from only powder ingredients.
- The leaching of Sb, Cu and sulphate of the artificial aggregate are well under the limit value, while chloride and Mo still exceed the limit value. The properties of the artificial aggregate can be modified by adjusting the proportion of ingredients used according to its application requirements.

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