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Integral recycling of municipal solid waste incineration (MSWI) bottom ash fines (0–2 mm) and industrial powder wastes by cold-bonding pelletization

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ABSTRACT

The cold-bonding pelletizing technique is applied in this study as an integrated method to recycle municipal solid waste incineration (MSWI) bottom ash fines (BAF, 0–2 mm) and several other industrial powder wastes. Artificial lightweight aggregates are produced successfully based on the combination of these solid wastes, and the properties of these artificial aggregates are investigated and then compared with others' results reported in literature. Additionally, methods for improving the aggregate properties are suggested, and the corresponding experimental results show that increasing the BAF amount, higher binder content and addition of polypropylene fibres can improve the pellet properties (bulk density, crushing resistance, etc.). The mechanisms regarding to the improvement of the pellet properties are discussed. Furthermore, the leaching behaviours of contaminants from the produced aggregates are investigated and compared with Dutch environmental legislation. The application of these produced artificial lightweight aggregates are proposed according to their properties.

1. Introduction

Nowadays, the sustainable development of building materials is attracting worldwide attention (Omer, 2008; Brunner and Rechberger, 2014) considering resource saving and environment protection. In industries and building materials field, reduce, reuse and recycle are the primary ways to achieve the environmental and economic sustainable development goals (Kothari et al., 2010; Ahuja, 1997). The use of industrial wastes is widely studied and successfully applied in some cases, and the inherent properties of these wastes show their suitability to be used as building materials (Rivera et al., 2015; Tam et al., 2005; Al-Jabri et al., 2009; Xuan et al., 2016a, 2016b). However, the application of some wastes is limited before proper treatments due to their environmental impact (Fedje et al., 2010; Arickx et al., 2006).

Municipal solid waste incineration (MSWI) bottom ash is a primary solid by-product from incineration plant, which has a potential to be used as building materials (Tang et al., 2015). Series of treatments are already available to clean the coarse bottom ash (above 2 or 4 mm) which make this coarse fraction suitable to be used as aggregate in concrete (Keulen et al., 2015). Nevertheless, the sand-sized bottom ash fraction (BAF, under 2 or 4 mm) remains to be a problem due to the fact that it contains higher amounts of contaminants (such as Cu, Sb and Mo) and salts (such as chlorides and sulphates) which exceed the leaching limits according to legislation (Tang et al., 2016). Landfill is not preferable due to lack of space, waste of potential resource and risk of leakage. Hence, suitable application and treatment are in demand. However, the efficiency of the current treatments on this sand-sized fraction is limited because of its small particle size and higher surface area (Rahman and Bakker, 2013) and the treatment cost is too high comparing with its application potential. Thus, new methods or applications should be explored for BAF. There are other industrial wastes, such as coal fly ash (FA), paper sludge ash (PSA) and washing aggregate sludge (WAS) which can be used or recycled as building materials (Mozaffari et al., 2009; González-Corrochano et al., 2010). Nevertheless, the environmental impact of contaminants is also one of the issues need to be considered during their application. Considering the solid wastes properties and their application potentials, an integrated recycling method is of interesting to be developed which can combine these wastes together, maximize their advantages (pozzolanic properties, etc. (Aubert et al., 2006), meanwhile minimize their disadvantages (leaching problems, etc. (Tang et al., 2015).

Currently, the cold bonded pelletizing technique is widely used to recycle industrial waste powders for producing artificial aggregates, and the raw materials (powder level) used are extended to

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various waste powders in recent years (Geetha and Ramamurthy, 2010a; Tsai, 2012; Gesoğlu et al., 2007, 2012; Thomas and Harilal, 2015; Dutta et al., 1997; Ferone et al., 2013). It is proved to be an effective way for recycling powdered wastes, however, there is hardly research done on the wastes which have a particle size larger than powder (<125 μm), such as sand-sized fractions (particles under 2 or 4 mm).

Hence, in this study, the cold bonded pelletizing technique is applied as an integral recycle method for municipal solid waste incineration (MSWI) bottom ash fines (0–2 mm, BAF), coal fly ash (FA), paper sludge ash (PSA) and washing aggregate sludge (WAS). Nowadays in the Netherlands, these solid wastes need to be used as useful/valuable materials instead of landfill, to reduce their environmental impact. An artificial lightweight aggregate is successfully produced based on this technique and the combination of the selected raw materials. Moreover, the influence of the raw materials on the properties of the aggregate and the methods to improve the aggregate properties are investigated. The leaching behaviour of these aggregates are evaluated and compared with Dutch legislation. Finally, the application potential of these aggregates is suggested.

2. Materials and methodology

The materials used in this study are shown in Fig. 1. The binder applied is Ordinary Portland Cement (OPC) CEM I 42.5 N (ENCI, the Netherlands). The industrial waste powders chosen here are combustion fly ash (FA), paper sludge ash (PSA) and washing aggregate sludge (WAS) from a power plant, a paper recycle company and a gravel washing factory in the Netherlands, respectively. The ground granulated blast furnace slag (Gao et al., 2015) (GGBS, ENCI, the Netherlands) is used as OPC alternative in one of the recipes. The municipal solid waste incineration (MSWI) bottom ash fines (BAF) are provided by a waste-to-energy plant in the Netherlands (Moerdijk, Attero.) which has around one million tonnes annual waste processing capacity of solid waste. The BAF has a particle size smaller than 2 mm, chosen by sieving from the wet MSWI bottom ash heap in the plant. Polypropylene fibre (PPF) with a length of 3 mm, density of 0.91 kg/m^3 provided by FBG (the Netherlands) and Bonar (England) is used as reinforced fibre.

The X-ray fluorescence (XRF, Epsilon 3, PANalytical) and the X-ray diffraction (XRD, Cu tube, 40 kV, 30 mA, 3–75°, 0.02°/step, 0.2°/min) are employed to determine the chemical compositions and crystalline phases present in the materials, respectively. The main chemical compositions (shown in Table 1) of these industrial wastes belong to the SiO_2-CaO-Al_2O_3-Fe_2O_3 system. The crystalline phases of the raw materials are shown in Fig. 2. WAS as a waste sludge from washing aggregate contains mainly SiO_2, and a considerable amount of Al_2O_3 and Fe_2O_3; the main crystalline phases in WAS are quartz, magnetite, clay mineral of the chlorite family, and feldspar. PSA consists high amount of CaO, and SiO_2 and Al_2O_3, its main crystalline phases are calcite, portlandite, gehlinite, and calcium silicate. The main chemical compositions in FA are SiO_2, and then higher amount of Al_2O_3 compared with the other waste materials in this study; its crystalline phases are quartz and mullite. BAF contains quartz, calcite, hematite, feldspar and anhydrite.

The particle size distributions (PSDs) of the powders are measured using laser diffraction (Mastersizer 2000 Malvern) and the PSDs of the particles (BAF and produced aggregates) are determined according to EN 933-2 (1995). BAF has a particle size under 2 mm, around 50% between 0.5 and 2 mm. GGBS has a very similar PSD as OPC, and WAS has a coarser PSD than OPC while similar as PSA. The PSD of FA is coarser than PSA (Fig. 3). The specific densities of the materials are measured using a helium pycnometer (AccuPyc II 1340) and shown in Table 1; and the bulk density of the produced aggregates are determined according to EN1097-3 (1998). The influence of PSA and FA on the OPC hydration is studied by eight-channel isothermal calorimeter (TAM Air, Thermometric).

The disc pelletizer (Fig. 4) is used for the pelletization process, the diameter of the disc is 100 cm and its collar height is 15 cm. The raw materials are homogenously mixed in a concrete mixer (BAF as received contains a water content of around 18%, it is used without drying), and then around 9–12 kg mixed material is fed to the disc. The water is sprayed during the first several minutes, and the disc is continuously running for the generation and compaction of granulates. The process is continuously running by adding mixed materials and then collect the produced aggregates which dropped off automatically in order to simulate the practical procedure in industry. The produced pellets are sealed in buckets at room temperature before test. By adjusting the pelletizing parameters (speed, angles, etc.), the particle size of the produced aggregate can be modified. The water absorption of the aggregates is determined according to EN 1097-6 (2013) and the crushing resistance of the aggregates is measured according to EN 13055-1 (2002) (Annex A, procedure 1). The cross sections of the pellets are observed using optical microscopy and scanning electron microscope (SEM, Quanta 650 FEG, FEI).

To estimate the environmental impact of the BAF and the generated aggregate, column leaching tests according to Dutch standard NEN 7383 (2004) were performed. The liquid to solid ratio is kept at 10 L/kg; during the test, the water is forced to flow through the material from the bottom to the top of the container

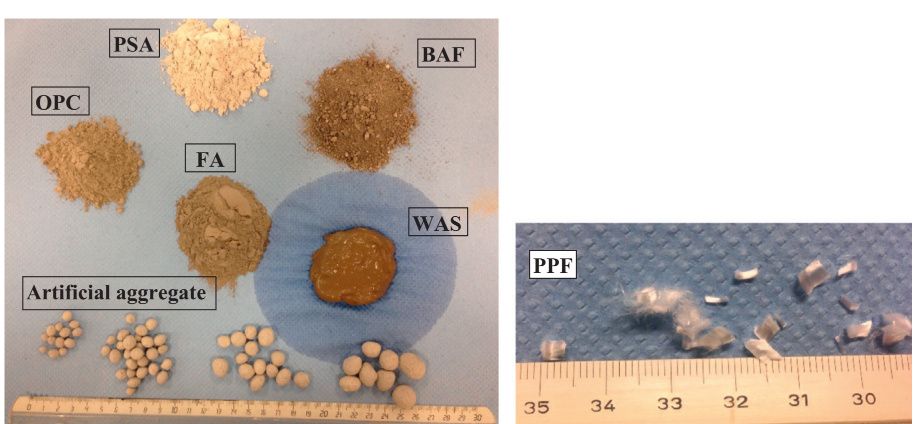

Fig. 1. The raw materials used and aggregate produced.