Bottom Ash Waste Management in Building Industry

Subjects: Engineering, Environmental
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MSWIBA development fits into the European Green Deal, Sustainable Development Goals (SDGs), and the Circular Economy (CE). The combustion of MSW in incineration plants generates more than 30% of secondary waste concerning the inlet stream. The main residue is MSW incineration bottom ash (MSWIBA), which accounts for ca. 90% of MSW incineration solid residues.

Keywords: secondary waste ; municipal solid waste incineration bottom ash ; circular economy

1. Introduction

In the United Nations Framework Convention of 1992, a position was adopted stating the danger of raising the average global temperature by 2 °C (or even 1.5 °C) above pre-industrial levels [1]. The solution to preventing an increase in temperature is the development of the circular economy and the departure from the current linear economy. According to the waste management hierarchy, products and materials are re-used and recycled in an ideal circular economy. Their life cycle is consistently extended and environmental pollution and greenhouse gas emissions are reduced [2][3]. **Figure 1** shows the circular economy in construction.

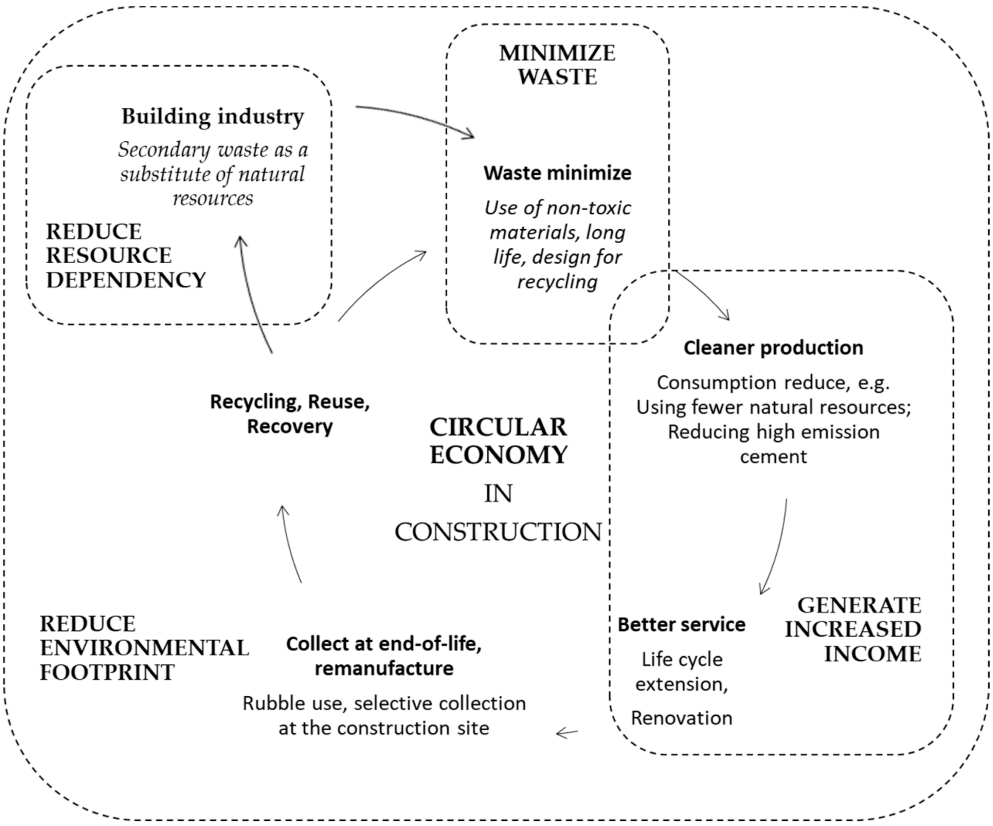

Figure 1. Circular economy in construction.

To improve the condition of the environment, the European Union introduced the European Green Deal [4]. The overarching goal of the European Commission's policy initiatives is to achieve climate neutrality in Europe by 2050. The Green Deal addresses challenges such as clean energy supplies, protection and restoration of the natural environment, sustainable development and use of natural resources, and improving human health. The goal of the Green Deal is to build and implement a framework for responsible, sustainable behavior and use of the natural environment [5][6]. From an environmental point of view, the most important Green Deal initiatives are related to: Transition to a Circular Economy;

Achieving Climate Neutrality; Clean, Reliable and Affordable Energy; and A Zero Pollution Europe. Each initiative has a strategy, a directive, and a specific course of action [7][8][9].

The green deal is integrated within the sustainable development goals (SDGs) adopted by the United Nations. The management of secondary waste in construction is in line with SDG 12 (Ensure sustainable consumption and production patterns) and SDG 13 (Take urgent action to combat climate change and its impacts), and can extend the life cycle of products or materials [7][10].

The use of secondary waste as a building material can contribute to achieving climate neutrality and lower pollution in Europe [11]. Using waste as a cement substitute is associated with lower greenhouse gas emissions (mainly CO_2) and reduced extraction of natural resources. Emissions related to the extraction, processing, and use of energy are avoided. To produce a ton of cement, almost one ton of CO_2 (dependent on technology) is produced [12].

2. Current Market Situation with Residual Waste and Secondary Waste

The last element of a circular economy is energy recovery. Combustion of mixed (non-recyclable) municipal solid waste (MSW) is part of Clean, Reliable, and Affordable Energy. MSW that cannot be recycled is landfilled, but this is not part of the circular economy [13][14].

An exemplary installation with a capacity of 210,000 tons per year and an average calorific value of incinerated waste at the level of 7.8 GJ/Mg (GJ/ton) produces 300.370 GJ of thermal energy and 405.166 GJ of electricity annually [12][15].

The combustion of MSW in incineration plants generates more than 30% of secondary waste concerning the inlet stream. The main residue is MSW incineration bottom ash (MSWIBA), which accounts for ca. 90% of MSW incineration solid residues. About 18 million tons are produced annually in Europe even with efforts to reduce waste incineration; hence. the amount of MSWIBA is much greater worldwide, such as in China, Japan, and Singapore [16]. MSWIBA is heterogeneous waste and it depends directly on input material (MSW). The raw MSWIBA consists mainly of melt components and stones (approx. 81%), pieces of glass (approx. 17%), porcelain (approx. 0.5%), metals (approx. 0.07%), and trace amounts of unburned organic material. The composition of the MSWIBA is variable and depends on the season, the location of the incineration plant, and even the day [12].

MSWIBA is characterized by compatibility with high elasticity in its uncured state. In the construction industry, MSWIBA, thanks to its properties, can replace natural aggregate and be used as a construction material. However, to be used in the construction industry, MSWIBA should be subjected to valorization and appropriate processes. Fresh MSWIBA is metastable and strongly alkaline reactive (e.g., it contains lime, and anhydrite). One of the methods of safe MSWIBA management, compliant with the Reference Document on the Best Available Techniques for Waste Incineration, is its valorization, generally achieved by the steps described in the following manuscript [12].

To improve the quality of MSWIBA as a substitute for natural aggregate, sand, or cement, the concrete matrix can be compacted or different activation can be used, for example: solidification, ceramization, keramization, vitrification, chemical activation (NaOH, $CaOH_2$, NA_2SiO_3 + NaOH, Na_2CO_3 + NaOH, NH_4OH), acid treatment with dilute solutions (HCl, H_2SO_4), chemical stabilization ($FeSO_4$, PO_4^{3-}), chelation, and other technologies depending on the needs, which are determined by the physicochemical composition and intended use of the end product. Ceramization and vitrification are high temperature processes and therefore are expensive, energy intensive, and non-environmentally friendly. Stabilization, solidification, and storage do not provide for recovery, and hence, do not fit into the circular economy. Other processes are still new, little known, and relatively expensive. This is why a market gap still exists; pilot and laboratory research is needed to fill this gap [8]. The MSWIBA is first cooled with water. Periodic storage of MSWIBA takes place under a roof or in a bunker for 1–3 months (sometimes the MSWIBA maturation/aging can take up to a year). The aging process causes hydration of metal oxides and oxidation of metallic Fe/Al. Then, the MSWIBA is divided into appropriate fractions (e.g., 0–40 mm and 40–150 mm fractions) by a rotary drum, and ferrous and non-ferrous metals are separated using magnetic separators. In this form, the MSWIBA matures further to allow the hydration processes to take place. The maturation process improves the physicochemical properties of the MSWIBA and reduces the leaching of heavy metals.

Bottom ash (BA, European Waste Codes: 19 01 12) is partly used as a priming method in the building industry [11]. Currently, the valorization process aims at improving physicochemical properties. The process consists in lowering the MSW incineration bottom ash (MSWIBA) temperature to 80–90 °C. Then, the MSWIBA is divided into 0–40 mm and 40–150 mm fractions in a rotary drum. The fractions are cleaned of ferrous and non-ferrous metals. The recovered metals are recyclable. Then, the fractions are prepared according to the recipient’s order (e.g., 0–8 mm and 8–40 mm). The pure fraction is aged under a roof to stabilize it. MSWIBA serve as ballast in a landfill as well [16][17].

Even after the described valorization process, the MSWIBA still contains mobile pollutants, e.g., heavy metals and salts, which are harmful to the environment. In addition, it contains substances that may have a negative effect on the concrete mix, such as metallic aluminum, glass, sulfur, chloride, and gypsum. Thus, using “raw” MSWIBA as a substitute for natural aggregate would produce a material with worse physical and chemical properties than the conventional one. Cracks and swelling are often noticed in concrete samples with the addition of MSWIBA due to its metallic Al or Al/Zn alloy content [18].

One possibility to reduce these adverse effects is to pre-treat the raw MSWIBA with NaOH. Equations (1) and (2) present the reactions of undesired Al and Zn, for instances, with NaOH:

$$2Al + 2NaOH + 6H_2O \rightarrow 2Na[Al(OH)_4] + 3H_2\uparrow \; pH > 11.75 \quad (1)$$

$$Zn + 2NaOH + 2H_2O \rightarrow Na_2Zn(OH)_4 + H_2\uparrow \; pH > 12 \quad (2)$$

NaOH pre-treatment reduces the leachability of MSWIBA impurities (e.g., As, Ba, Cr, Cu, Pb, Ni, Se, Zn, Al, Al/Zn) and improves building properties. An important parameter for this pre-treatment is the concentration of NaOH. The use of a solution below 0.1 mol/L NaOH may not be effective. Due to the seasonality and heterogeneity of MSWIBA, to select the optimal concentration of the NaOH solution, a specific batch of material should be previously tested, mainly for its content of Al and Zn, to provide for the proper amount of NaOH as indicated by the stoichiometry in the given reactions (1) and (2) [18].

The course and effectiveness of the NaOH pre-treatment process depends not only on the concentration of NaOH, but also on the temperature and duration of the process [18][19].

To improve the pre-treatment, the stabilization time can be extended. However, some researchers have shown that the compressive strength can be increased with the appropriate ratio of aggregate to MSWIBA and if water pre-treatment is used [18].

In previous work, researchers investigated how different mass ratios of MSWIBA to aggregate values influence the compressive strength of cement [10]. The best compressive strength value was obtained for a MSWIBA/aggregate equal to 10%; however, any mixture of MSWIBA and aggregate showed better values than without MSWIBA. In normal circumstances, cement setting comes to strength standard in 28 days. It is estimated that 75% of the cement reacts during the maturation period. In the MSWIBA case, the setting takes longer, wherein after 90 days or more, compressive strength will probably be increase [20][21].

Researchers aim to check how leachability in different environments (acid, alkali, aggressive, and normal) changes for mortars prepared with different types of MSWIBA. In particular, the mortars were prepared with addition of MSWIBA before valorization, after valorization, and after NaOH pre-treatment.

3. Life Cycle Assessment (LCA)

Every time a new process is proposed for recycling or recovery a waste stream, it is almost compulsory to check whether the new process effectively offers environmental improvements compared to conventional processes by performing a Life Cycle Assessment (LCA) [22].

Several authors have attempted to carry out an LCA of various MSWIBA management methods and the results indicate that the use of slag after waste incineration is associated with a positive environmental impact [23][24][25].

Results from one author noted up to 19% cost savings from waste-derived alkali-activated mortar in comparison to conventional alkali-activated mortar. Authors predict that chemically modified waste-derived activators are a promising alternative for improving the environmental performance of alkali-activated materials if their usage also reduces or replaces the need for conventional alkali-activators [25].

Researcher aims to provide a preliminary evaluation of the environmental impacts or benefits of using NaOH treatment for the alkali activation of MSWIBA by LCA.

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