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Municipal incinerated bottom ash characteristics and potential for use as aggregate in concrete

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HIGHLIGHTS

- Global data on MIBA as aggregate in concrete analysed and evaluated.
- MIBA use as fine or coarse aggregate in mortar, concrete, blocks, foamed mixes.
- Lightweight aggregate produced using MIBA and subsequently used in concrete.

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ABSTRACT

The use of municipal incinerated bottom ash (MIBA) as aggregate in concrete applications has been assessed through the analysis and evaluation of the globally published data. After appropriate pre-treatments, MIBA can be used as fine or coarse aggregate in mortar, concrete and blocks. Full-scale operations have been undertaken with success, mainly in blocks. MIBA lightweight aggregate had similar properties to Lytag, though with marginally lower strength. Concrete containing MIBA lightweight aggregate achieved low density, high consistence properties, with strengths just below Lytag mixes. Replacing sand in foamed concrete, MIBA mixes satisfied the high flowability, low strength requirements.

1. Introduction

Municipal incinerated bottom ash (MIBA) is the main residue resulting from the incineration of municipal solid waste (MSW). As waste management continues to move away from landfilling, incineration is becoming an increasingly important treatment option. The process involves the recovery of energy from the waste combustion and results in large reductions in the quantity of material to manage, decreasing by approximately 70% by mass – of which 80–90% is bottom ash and the remainder is fly ash and air pollution control residues.

Annual MSW production rates of 241 MT in the 28 European Union countries ([26] – data from 2014), 654 MT in the 34 OECD countries ([52] – data from 2014) and 1840 MT worldwide ([86] – data from 2012) have been reported. Data for MIBA production is limited, though in the European Union, 27% of the MSW was reported to be incinerated ([26] – data from 2014) and on this basis, it is estimated that 16 MT of bottom ash are generated per annum.

The quantity of MIBA produced presents a significant management problem, however as a useful secondary resource for potential use in construction, the material offers great opportunity. European countries such as Belgium, Denmark, Germany and The Netherlands are taking advantage of this potential, using 100, 98, 86 and 80% of the MIBA produced, respectively, predominantly as fill and road construction materials [4,61]. Around half of the MIBA generated in the UK is used in construction, including as an aggregate in concrete blocks [21,35,61].

The use of MIBA in concrete related applications is an area where there has been a strong research interest, yet the practical application is not as far progressed as its use in road pavements.

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Concrete is recognised as one of the most widely used construction materials, though carries a high carbon footprint, with cement production accounting for around 8% of the global CO_2 emissions [48]. With increasing emphasis on sustainable development, major changes are required to reduce the emissions associated with cement production and conserve natural materials through the incorporation of secondary and recycled materials in concrete. The characteristics of MIBA suggests that it has potential for use as both aggregate and cement (in ground form) components in concrete, offering a high value use of the ash, though typically with onerous material requirements. Its use as aggregate as a substitute for natural sand and gravel in concrete related applications is the particular focus of this paper.

2. The project

This project examines the characteristics of MIBA and its potential for use as an aggregate in concrete related applications through the analysis and evaluation of the global experimental results. The aim is to establish current status of the material and advance its safe and sustainable use as both coarse and fine aggregate components in a range of applications: mortar, concrete, masonry blocks, lightweight aggregate concrete and foamed concrete.

The data was managed in two parts, with the first dealing with the characteristics of MIBA. Results on the material properties were provided as a matter of routine in a huge number of studies, which explored the use of MIBA in all types of construction applications. To avoid overwhelming the messages in the text, those references containing solely numerical data on characteristics of MIBA were listed in the Supplementary data. The second part of the data is on the use of MIBA specifically as an aggregate in concrete related applications. This research on concrete has been published over a time period of 40 years and carried out in 18 countries across Europe, Asia and North America (Fig. 1). Beginning in 1979, this research was produced intermittently up until the late 1990s, after which the rate of publication increased and in particular, a large amount of work has been undertaken in the last three years. Over half of the work has originated in Europe, whilst the largest individual contributions have come from the UK, USA and Taiwan.

3. Material characteristics

3.1. Grading

As-produced MIBA contains metallics, ceramics, stones, glass fragments and unburnt organic matter, with particles sizes ranging up to 100 mm, though the oversized fraction, 30/40/50 mm, is customarily removed as part of a standard screening process. Further changes to the grading of MIBA arise from the subsequent processing adopted, depending on the plant operation and end-use of the material. This has included further sieving, grinding, ferrous and non-ferrous removal, size separation, thermal and chemical treatment.

Particle size distribution curves are presented in Fig. 2 for MIBA samples used in concrete related applications that were screened or sieved as an aggregate component (references in Appendix A), along with the grading curves for the BS EN 12620 (2013) fine aggregate limits.

Screened MIBA samples are shown to be well graded, containing mostly sand and gravel sized particles, with a low silt fraction. The grading of MIBA was most commonly adjusted by removing the gravel fraction in sieving to produce a suitable fine aggregate component.

3.2. Density

The material has been found to have an average specific gravity of 2.32, based on the total data (references in Appendix B) and this categories the material as less dense than typical values of 2.65 for natural sand, though above the 2.15 value of furnace bottom ash [73]. Bulk density results ranged from 510 to 2283 kg/m^3, with an average value of 1400 kg/m^3 (14 samples. Appendix B), which is comparable to loose sand [37].

As presented in Fig. 3, the density MIBA samples can also be further sorted into three groups based on how the material is processed:

(a) Samples screened or unspecified processing – Average specific gravity of 2.37, with most in the range from 2.2 to 2.5.
(b) Samples sieved as fine aggregate – Average specific gravity of 2.34, though most samples had lower densities than category (a) samples. Additional results given per size fractions of the MIBA samples [28,30,33,71,90] supported the finding that the fine fractions of MIBA are less dense than the coarse fractions.
(c) Samples subjected to metal recovery treatment such ferrous and non-ferrous metal removal and washing – Decrease in the density is evident, average specific gravity of 2.2, due to a reduction in the heavy elements such Al, Cu, Fe and Pb. The higher specific gravity of two samples in this group (2.47 and 2.65) can be attributed to additional grinding treatment, which reduced porosity and increased density.

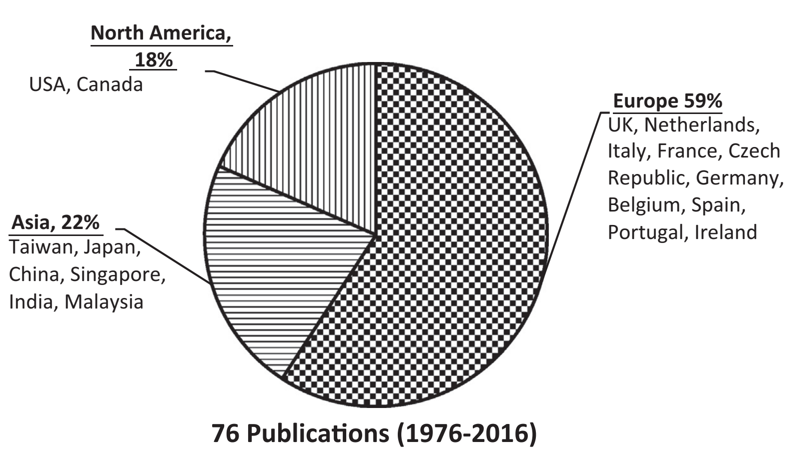

Fig. 1. Continental and country-wise distribution of publications on MIBA in concrete applications.