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Technological and environmental behavior of sewage sludge ash (SSA) in cement-based materials

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Abstract

Sewage sludge ash (SSA) is a waste material obtained from the incineration of wastewater sludge. The physical, chemical and mineralogical characteristics of SSA, and the evaluation of its use in cement-based materials, are presented in this paper. Results show that SSA is composed of irregular grains having a high specific surface area and thus leading to a significantly high water demand. A fraction of the ash is rapidly soluble (sulfates, aluminum and silica) and can create new-formed products in presence of lime. SSA induces short delays of cement hydration, probably due to both minor elements of the ash and dilution effect. Compressive strengths of mortars containing 25% and 50% of SSA are always lower than those of reference mortars but it is shown that SSA has a long-term positive effect which might be related to a slight pozzolanic activity. The amount of elements leached from SSA mortars is slightly higher than from the reference mortar without residue but it remains of the same order of magnitude. An extensive literature review was performed in order to compare the residue used in this study with others included in the same category. This analysis highlighted the principal characteristics that must be taken into account to use SSA correctly in cement-based materials.

Keywords: Sewage sludge ash; Characterization; Mineral admixture; Leaching; Waste

1. Introduction

The total production of sewage sludge for the United States of America (USA) and countries of the European Union (EU) approaches 17 Mt of dry solids per year (7 Mt in USA + 10 Mt in EU) [1]. The management of these sewage sludges between incineration, agricultural uses and landfill is reported in Fig. 1 [1–4]. Considering that between 300 and 400 kg of ashes are produced per ton of dried sludge and that a fraction of these sludges are incinerated (around 22% in USA and a mean value of 15% for the EU countries), it is obvious that about 1.2 Mt must be managed each year in USA and EU. This quantity is much smaller than that of other by-products such as coal fly ash (70 Mt and 44 Mt produced in USA [5] and EU [6] in 2003, respectively), which may explain the relatively limited research done on the recycling of SSA. Another reason for the lack of publications may be related to the fact that management of sewage sludge by incineration processes is recent, as it was previously reused in agriculture.

Some research work has already been done on the use of this waste in construction materials, e.g. as a filler in asphalt concrete applications [7,8], bricks and tiles [9–22], raw material in a cement kiln [23,24], or for the manufacture of aggregates and lightweight aggregates [9,25–33]. The use of SSA in cement-based materials as cement or sand replacements is also reported in a few recent studies [34–57]. In a general way, these studies show that SSA reduces the workability of fresh mortars and tends to increase the setting time of cements [36,38,41–46]. Most studies also report a decrease of compressive strength of mortars and concrete when SSA is used as a cement or sand replacement: about 30% of decrease in the worst case found in the literature for 10% SSA [52]. Only a few authors have shown a strength similar to or greater than the reference with up to 5 [38], 10 [9] or even 15% [56] of SSA in mortars. Since SSA is a waste material, attention must be paid to its environmental impact when it is reused in other applications. However, little information is available about the environmental impact of SSA in cement-based materials [56] and no comparison has been

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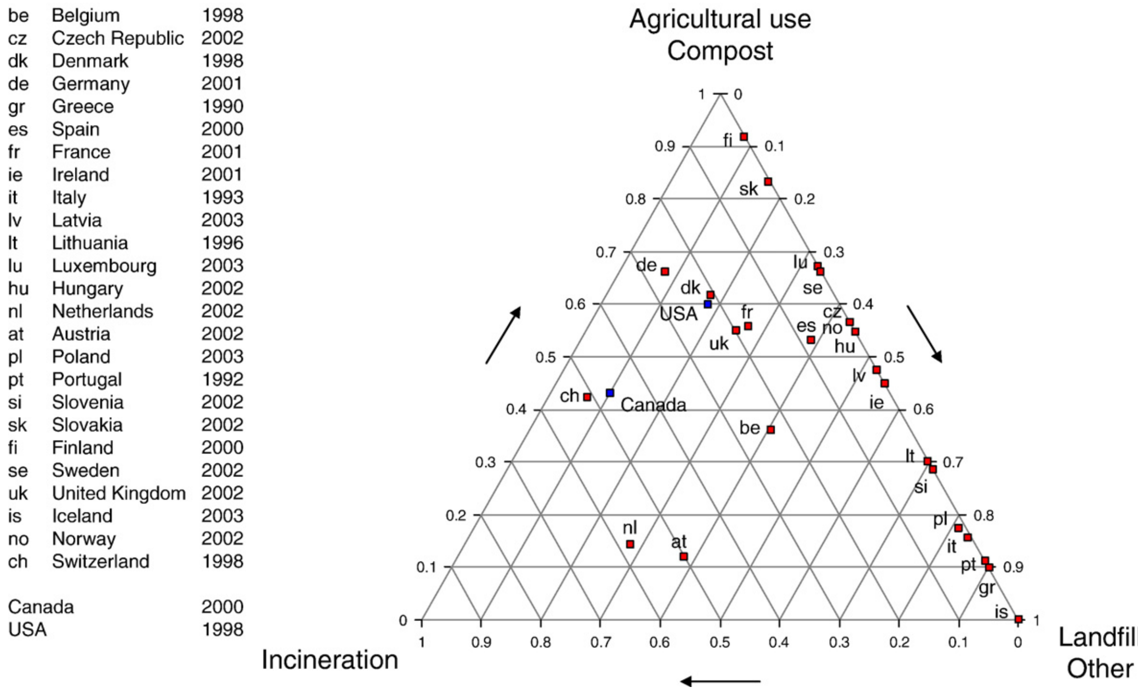

Fig. 1. Disposal of sewage sludge between incineration, agricultural use and landfill for European countries, Canada and United States. The years represent the last available data for each country [1–4].

made with reference concrete, so it is not possible to evaluate the pollutant potential of SSA.

A literature analysis shows that the effects of SSA on mortars and concrete properties are more or less noticeable, depending on the characteristics of the specific SSA used in each study. The inherent variability of this kind of residue remains one of the most important reasons for avoiding a systematic generalization of the results. So the aim of this work is to provide supplementary knowledge about the characteristics of SSA and its effect on the properties of cement-based materials. The results are then compared to those found in the literature in order to compare the residue of this study with others included in the same category. Considering the origin of SSA, its environmental impact is also evaluated. The analysis of the results should

Table 1
Experimental methods for the physical and chemical characterization of SSA, and for the study of the activity of SSA in cement-based materials

Property	Test method/standards
Density	Hydrostatic weighing
Particle size distribution	Laser granulometry
Specific surface area	Blaine (NF EN 196-6), BET (nitrogen)
Morphology	Scanning Electron Microscopy (SEM), coupled with elemental analysis (EDX)
Chemical analysis	Atomic adsorption with flame atomisation (major oxides)
	Inductively coupled plasma-mass spectrometry ICP-MS (minor elements)
Selective dissolution	Successive HCl and KOH attack
	−40 ml of HCl (37%)
	−100 ml of KOH (250 g/l)
	Soluble fraction (acid and base) NF EN 196-2
Mineralogy	X-ray diffraction (XRD); Co Kα radiation (λ=1.789 Å)
	2θ step interval of 0.02° (5°–70°) and acquisition time of 10 s
Reactivity	
–with water (hydraulic reaction)	XRD of mixtures ash–water
–with lime (pozzolanic reaction)	XRD of mixtures $Ca(OH)_2$–ash–water (4:1:4 in mass)
Effect on cement hydration	
–mineralogical study	XRD of mixtures cement–ash–water
–setting time	Setting time using Vicat apparatus (NF EN 196-3)
–heat evolved	Semi-adiabatic (Langavant) calorimeter (NF P 15-436)
Effect on workability of mortars	Flowing under vibration using LCL apparatus (NF EN 12350-1)
Effect on mechanical properties of mortars	Compressive strength of 4×4×16 cm prisms (NF EN 196-1)
	Hydration times: 1,7,28,84 days; Each value is the average of 6 tests
Effect on environmental behavior of mortars	Leaching tests on monolithic mortars (NF P X31-211) and on crushed mortars (EN 12457-2)