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Sewage sludge/biomass ash based products for sustainable construction

Primož Pavšič [a,*], Ana Mladenovič [b], Alenka Mauko [b], Sabina Kramar [b], Matej Dolenec [c], Ernest Vončina [d], Katarina Pavšič Vrtač [e], Peter Bukovec [f]

[a] Building and Civil Engineering Institute ZRMK, Dimičeva 12, 1000 Ljubljana, Slovenia
[b] Slovenian National Building and Civil Engineering Institute, Dimičeva 12, 1000 Ljubljana, Slovenia
[c] University of Ljubljana, Faculty of Natural Sciences and Engineering, Aškerčeva 12, 1000 Ljubljana, Slovenia
[d] Institute of Public Health Maribor, Prvomajska ulica 1, 2000 Maribor, Slovenia
[e] University of Ljubljana, Veterinary Faculty, Institute for Hygiene and Pathology of Animal Nutrition, Gerbičeva 60, 1000 Ljubljana, Slovenia
[f] University of Ljubljana, Faculty of Chemistry and Chemical Technology, Aškerčeva 5, 1000 Ljubljana, Slovenia

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ABSTRACT

The aim of this research was to determine how best to utilize two environmentally challenging types of waste: sewage sludge, and a particular type of waste ash, biomass ash, which is obtained from biomass combustion processes. The results of the performed research have shown that liquid sewage sludge can, in fact, be successfully stabilized with biomass ash, so that a stable composite material can be obtained, having a compressive strength within the range between 0.5 to 2.5 MPa, with "Controlled Low-Strength Material" properties. During the stabilization process, the microbial activity of sewage sludge is inhibited, due to raised pH levels and temperatures. Analysis of the chemical composition of water leachates from samples of the composite showed that it is inert, and thus does not pose a threat to the environment. The observed decrease, over time, in the concentrations of the pollutants indicated that the latter are immobilized in the hydrated matrix, due to the formation of new hydration products, i.e. mono- and hemi-carboaluminate and Friedel's salt, and changes associated with pore diameter and distribution. The addition of selected types of recycled aggregates, to the above-described composite material was also investigated, and it was found that a useful material having similar properties could be obtained. This means that such composite materials could be used as low flow material or back fill, road base stabilization material and bedding material for pipes and cables, as well as for daily or intermediate landfill covers. From the point of view of sustainable development, this kind of waste management presents an optimum – zero waste solution, since it results in the cleaner production, while preserving natural resources, reducing CO_2 emissions, and lowering the costs of sewage sludge management.

1. Introduction

With the improvement of urban waste water collection and treatment in the European Union after the implementation of the Urban Waste Water Treatment Directive 91/271/EEC (EEC, 1991) a significant increase in sewage sludge production was observed (Kelessidis and Stasinakis, 2012; Valderrama et al., 2013). It is estimated that annual sewage sludge production in the EU will, by 2020, exceed 13 million tonnes of dry solids (Léonard, 2011; Milieu Ltd. et al., 2010).

Due to its high organic content, contamination with heavy metals (Eurostat, 2012a; Hong and Li, 2011), and the presence of pathogenic bacteria (Husillos Rodríguez et al., 2012; Kelessidis and Stasinakis, 2012) and organic pollutants (Houdková et al., 2008; Zhu et al., 2011), sewage sludge from urban waste water treatment plants poses a major environmental problem. According to the Eurostat report (Eurostat, 2012a), up-to-date biodegradable sewage sludge management mainly consists of four different types of disposal methods: reuse in agriculture, composting, incineration for volume minimization or energy utilization, and landfilling. Reuse in agriculture is the most widely adopted practice in Spain, Ireland, Lithuania, Hungary, Bulgaria, Cyprus, Luxembourg, France, the Czech Republic and Norway, whereas in Estonia and Slovakia a considerable proportion of the total volume of sewage sludge is treated through composting. Incineration of sewage sludge has

* Corresponding author. Tel.: +386 31 325 750.
E-mail address: primoz.pavsic@gi-zrmk.si (P. Pavšič).

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been reported as a primary pathway for disposal in the Netherlands, Slovenia, Belgium, Germany, Austria and Switzerland. Discharge into controlled landfills is still practised as the primary pathway in Greece, and used exclusively in Malta (Eurostat, 2012a).

The reuse of sewage sludge in agriculture is often made more difficult to implement due to the presence of bacteria and heavy metals (Eurostat, 2012a; Qi et al., 2011). In incineration procedures, even though these have undergone significant improvements, several factors concerning the treatment of flue gases and ashes, the emission of dioxins, furans, and heavy metals, and the handling of residues, represent a severe threat to the environment (Fytili and Zabaniotou, 2008), whereas landfilling, as the least favoured option (EP and CEU, 2008), continues to damage the environment. To a minor extent, other methods, such as pyrolysis, temporary storage, long term storage, reuse in green areas or forestry as fertiliser (Romero et al., 2013), landfill cover (Herrmann et al., 2009; Kelessidis and Stasinakis, 2012), as well as use in construction (Barrera-Diaz et al., 2011; Cusidio and Cremades, 2012), have been reported. Because of wide application possibilities and high material demand, the use of sewage sludge in construction is one of the most interesting options. The majority of management practices used for the treatment of sewage sludge, including those in which such sludge is treated for construction purposes, involve dewatering or thermal drying, in order to obtain 20 wt% or more of dry solids (Ländell et al., 2012; Rodríguez et al., 2013). However, these treatments are costly (Furness et al., 2000; Murray et al., 2008) and energy-consuming. This is why the solidification/stabilization of sludge prior to dewatering (with total dry solids typically around 5 wt% (Fytili and Zabaniotou, 2008)) seems to be, with respect to sustainable development, an optimum alternative solution. These technologies are processes in which waste materials are mixed with various binding materials in order to obtain, on the one hand, new and useful composite products (Xu et al., 2008), while, on the other hand reducing the mobility of incorporated pollutants and thus also the potential threat to the environment (Chen et al., 2009).

One, in the authors' opinion very promising material, which could be used in order to develop a synergistic approach to the problem of sewage sludge is ash, whose worldwide annual production has been estimated to be, at the present time, approximately 476 million tonnes (Vassilev et al., 2013). Due to the increase trend of biomass exploitation (Eurostat, 2012b), this quantity may be expected to increase significantly in the near future. Some types of such residues, such as fly ash (Al Bakri et al., 2011; White, 2005), coal bottom ash (Katz and Kovler, 2004), and municipal solid waste incinerator bottom ash (Lam et al., 2010; Li et al., 2012), have already been successfully used as binders in the field of construction, whereas ash obtained from biomass combustion is not widely used.

Based on the results of recent research (Černec and Zule, 2007; Pavšič et al., 2013) it is possible to manage sewage sludge and biomass ash within the scope of a single process, so that a new composite construction material, exhibiting the characteristics of "Controlled Low Strength Materials" (CLSM) (CCAA, 2008a; Trejo et al., 2004), and usable for many purposes, can be obtained. Recycled aggregates from construction and demolition waste, as natural aggregate substitutes, or indeed natural aggregates themselves, can also be incorporated in such new composites. CLSM refers to a cementitious material, whose characteristics are similar to those of stabilized soils, and which permits re-excavation afterwards, if necessary (Gabr and Bowders, 2000; Zhen et al., 2012). Because of reduced labour and equipment costs, faster construction and the possibility of applications in places with restricted access for compaction machinery, these materials continue to gain importance in applications such as bedding materials for pipes and cables, void-filling and backfilling utility trenches, bridge abutments, foundations and retaining walls (Trejo et al., 2004; Zhen et al., 2012). In order to be able to successfully replace the traditional materials for CLSM with such new composite materials, the later must be environmentally inert, must not pose a health hazard, and must exhibit the desired consistency or flowability, with a setting time of 1–5 h, as well as having a compressive strength of 0.5–2.5 MPa after 28 days of curing (Rajendran, 1997). The aim of this work is to present the beneficial utilization of sewage sludge, biomass ash and recycled aggregates in the production of construction composites with CLSM properties, showing their applicability and environmental acceptability, and thus providing a basis for zero waste and cleaner production.

From the sustainability point of view, this kind of waste management presents an optimum waste management solution, while preserving natural resources and reducing CO_2 emissions. However, efforts still have to be made to address the global warming potential issue (Johansson et al., 2008; Liu et al., 2011).

2. Materials and methods

2.1. Materials

Sewage sludge (SS), which is the fluid component of the studied composite materials, was obtained from an aerobic biological waste water treatment plant (dispersed biomass), which belongs to the VIPAP Slovenian paper-mill company, where both industrial and municipal waste waters are treated. Samples of sludge, in total amounting to 100 L, were taken from the aeration basin, before dewatering began.

The biomass ash (BA), which was used as a binder in the preparation of the composite materials, originates from the same paper mill company, and represents the combustion residue from a steam boiler, where de-inking fibre paper sludge, waste wood, and bark are used as a fuel. Approximately 100 kg of the BA, which was needed for the research, was collected from a 300 m^3 silo.

Recycled aggregates (RA) with gradations 0/2 mm and 0/8 mm produced at the recycled aggregate producer Žuran d.o.o. were sampled in a quantity of 50 kg and tested for size distribution and petrographic composition.

Two types of composites were studied. One was a composite prepared from SS and BA, designated as SAC ("sludge-ash-composite"), and the other was the same composite with the difference that RA with nominal gradations of 0/2 mm (RA-0/2) and 0/8 mm (RA-0/8) was added to the basic SAC mixture (samples of this type were designated as SAC-0/2 and SAC-0/8, respectively, referring to the gradation size used).

2.2. Experimental methods

2.2.1. Characterization of materials for the preparation of the composites

The materials used in the preparation of the studied composites were characterized.

The basic parameters of the SS, such as pH and conductivity, as well as those of the dry residue (according to SIST EN 12880:2001) were first determined.

Because of the potential bacteriological contamination of the SS, its microbiological quality was assessed by the aerobic mesophilic bacteria count method, which is based on the standard test method for determining water quality according to ISO 6222:1999. For this purpose 1 g of the sample was diluted, under aseptic conditions, in 100 mL of a sterile Ringer solution and spread on a Standard Plate Count Agar. After incubation for 2 days at 37 °C, a colony forming units (CFU) count was performed.