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SUITABILITY TESTS OF FLY ASHES VITRIFICATION FROM SEWAGE SLUDGE INCINERATION

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Abstract: The paper presents the results of preliminary studies on the properties of products made by vitrification of waste containing fly ashes from sewage sludge incineration. The performed tests of hazardous substances leached from the ashes, as well as the results of other laboratory tests confirmed the efficacy of vitrification. It has been found that the resulting products (sinters) could be used as a substitute aggregate for road foundations.

INTRODUCTION

Vitrification is an effective method of the disposal of hazardous waste which contains heavy metal compounds. The process involves the formation of an impermeable and durable layer of glass. The generation of the stable glassy coating requires heating of the substances to temperatures of 1300–1450°C and then rapid cooling. The process also destroys organic compounds, which are often found in the waste. Providing a substantial portion of thermal energy, however, involves high costs of the process, limiting its widespread use.

The products manufactured by vitrification are characterized by high resistance to leaching of hazardous substances and high resistance to mechanical damage, so it is advisable to use ceramics in industry and construction. This method is commonly used for the utilization of radioactive waste from nuclear plants [11]. Increasingly, it is also applied in making use of ashes from power plants or from the incinerators, tannery sludge and tailings, waste containing sulfur compounds, lead and other elements [1, 6, 7, 16].

We commonly apply fine fraction vitrification of waste without any special additives in heating crucibles. Increasingly, we modify this procedure by adding grain composition of substances lowering the melting point with the consolidation of fine-grained solid fraction in certain shapes and sizes [9, 15, 17]. A scheme of the procedure conducted in this study is shown in Figure 1.

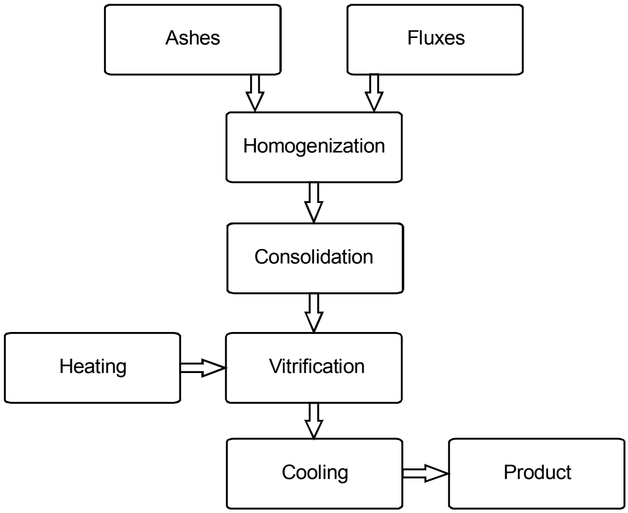

Fig. 1. Schematic process of fly ash utilization with the use of citrification

The main advantages of vitrification process are:

- decomposition of organic matter,
- structure of the inorganic components “built” in the glass,
- reducing the volume of vitrified material,
- chemical resistance of the product obtained.

Vitrification process involves melting the material in a high temperature heating furnace, and then quick cooling in cold water to convert the resulting liquid phase into the glassy structure. The energy expenditure depends on the type of material and furnace used. The resulting homogeneous glassy substance is characterized by high mechanical strength, low chemical reactivity and non-toxicity. Using waste vitrification of certain substances having the characteristic traits of the products enable them to be re-used mainly in construction [4, 15].

Advanced vitrification waste may be toxic and may have very complex chemical composition, as well as unfavorable physical properties. It is usually difficult to be utilized by products of industrial processes such as radioactive waste [11]. So far it has been possible to vitrify such wastes as fly ash, slag, radioactive waste, medical waste, asbestos etc. [3, 8, 13, 14].

A big problem is the sanitation of polluted soils [2]. Due to the high content of silicon, aluminum and other elements that the ground consists of, it is a good material for vitrification [3]. More and more frequently fly ash from the incineration of municipal waste and sewage sludge is subjected to vitrification [5, 10, 12, 15].

MATERIAL CHARACTERIZATION

In the initial suitability tests for vitrification method fly ash from the incineration of sewage sludge was selected from municipal wastewater treatment plant “Hajdów” in Lublin. These deposits contain large amounts of periodical compounds of heavy metals and pathogenic organisms, which hinder their agricultural use. Table 1 summarizes the approximate content of heavy metals in sewage sludge under consideration.

Table 1. Heavy metals in sewage sludge from wastewater treatment "Hajdów"

Element	Typical content [$mg \cdot Mg^{-1}$ d.m.]	Maximum content [$mg \cdot Mg^{-1}$ d.m.]
Lead	200 – 500	3000
Cadmium	10 – 20	200
Zinc	3000 – 4000	7000
Copper	200 – 500	1200
Nickel	200 – 300	800
Chromium	300 – 500	5500

Waste taken for study and settlement was thermally dried and combusted using fluidized bed boiler equipped with exhaust gas cleaning system. Fluidised bed combustion provides low organic matter content in ash not exceeding 3% of the mass. Ash samples were taken from the silo, where they were discharged pneumatically after capture by electrostatic precipitators.

The ash from the incineration of sewage sludge is in the form of fine mineral dust, from light to dark grey and light brown colour. The components of ash are primarily oxides: SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, K_2O i TiO_2 (Table 2).

Table 2. Major chemical components of the analyzed ashes

Ash components	SiO_2	Al_2O_3	CaO	Fe_2O_3	SO_3	K_2O	Na_2O	other
Share weight [%]	39.34	17.72	15.20	5.32	5.11	1.98	1.28	14.05

On the surface the ash particles condense and heavy metals are absorbed by polycyclic aromatic hydrocarbons (PAHs). Harmful compounds are washed from the surface of the particles, which then penetrate into the soil and groundwater. For this reason, there is a need for protection against dusting of ash landfills and isolation of secondary groundwater pollution.

METHODOLOGY

In order to prevent environmental pollution it is suggested to agglomerate ashes to a solid form, to solidify them with cement or vitrificate them at high temperature. The solidification of ashes in the compositions allows to use blocks of cement in the construction of underside layer of roads, deep foundations and municipal housing landfills. As a result of concrete structures corrosion there is a danger of leaching of toxic substances contained in the ashes. To prevent the elution of molded cement they are covered with a layer of a hydrophobic, such as tar or asphalt.

Vitrification of ash can produce a glassy structure on the surfaces of agglomerated solids. Dangerous substances are “closed” within the solids, i.e., sealed by the glassy structure that can not be released under the influence of external environmental factors. Vitrification can create the most hazardous waste, containing heavy metals and their compounds.

The study of vitrification usefulness determined the disposal of fly ash from the sewage sludge incineration. The procedure involved homogenization of ashes mixed with additional ingredients, mixing portions merged into a single sample, then heating in a laboratory chamber furnace and rapidly cooling the product.

The homogenized mixture contains fly ash in an amount of about 50% by weight, silica dust (about 40% by weight) and crushed waste glass (about 10% by weight). Silica fume (waste from the production of siliceous aggregates) and glass waste were added in the form of dust by up to 0.2 mm fraction. Silica fume in the synthesis process creates a thermal structure of the silicate, in which the heavy metals found in ashes are contained, combined in a sustainable manner. Glass waste (from used lamps and glass lighting businesses) is in the form of flux and have a similar structure to silica dust. Their use is preferred due to lower thermal reaction temperature.

The process of homogenization of the mixture involved mixing of the ingredients in a mixer paddle and adding portions of water until the consistency of humidity reached 5–6%. After homogenization the mixture was compacted by the stamp hydraulic press to be given a cylindrical shape, whose volume was about 14 cm^3. These compacts were sent to a laboratory chamber furnace with a capacity of 1400 W. Heating was performed at 1100°C for 60 minutes. After the warm-up the products were cooled in a bathtub filled with water, and then they were tested for their fitness for use. The studies identified:

- mechanical strength,
- frost resistance and water absorption,
- leaching of hazardous substances.
- energy consumption of the process.

Mechanical strength of sinters acknowledged was based on the measurement of compact breaking load, as well as resistance to gravity drop. The value of the load force causing damage to the product was determined experimentally by placing horizontally between the flat surfaces of hydraulic testing machine and squeezing until the destruction of its structure. The device resistance for gravity discharge was assessed by percentage of weight loss after three batches of samples dropped from the height of 2.0 m onto a 20 mm thick steel plate.

Frost was studied with use of a indirect method specified by the Polish standard PN-88/B-06250. The study involved cyclic freezing and defrosting in the air and in the water. One cycle lasted 6 hours, and the sample was subjected to three such cycles. Then it was tested for compressive strength of sintering. The degree of frost resistance was based on the ratio of strength to weight loss.

Absorbability study, i.e., the ability to absorb water through the material at atmospheric pressure, involved gradual immersion in water samples. Absorbability was defined as the ratio of mass of water absorbed to the mass of dry sample material.

Leaching of hazardous substances, such as chromium, cadmium, copper, lead, nickel, zinc and mercury was studied by plasma emission spectrometry method.

Energy intensity of the process was determined by the measurement system consisting of a voltmeter, ammeter and a clock measuring the time of sintering. Energy demand in the vitrification of ash was calculated from the formula:

$$E = U \cdot I \cdot t \text{ [J]} \quad (1)$$

where: U – voltage [V], I – current rate [A], t – sintering time [s].

After substituting the data we obtained:

$$E = 230 \cdot 5 \cdot 3600 = 4\ 140\ 000 \text{ J} \approx 4{,}1 \text{ MJ} \quad (2)$$

The above formula gives a result which includes the approximate energy required to melt a batch of 1 kg (20 pcs samples) and the energy needed to cover the heat loss of laboratory furnace chamber.

RESULTS AND DISCUSSION

In the studies of individual samples we have found high repeatability of measurements of physical and mechanical properties. Analysing the results presented in the following tables we can state that they have high strength values of the load and resistance to discharge by gravity of the vitrification (Table 3).

Table 3. Product properties after vitrification

No.	Parameter	Unit	Measured values	Acceptable content
1.	Compression strength	MPa	4.5	> 2.5
2.	Resistance on gravitational drop	%	92.1	> 90.0
3.	Bulk density	$Mg \cdot m^{-3}$	520.0	400.0 – 550.0
4.	Freeze resistance	%	1.1	< 2.0
5.	Absorbability	%	15.2	< 37.0
6.	Energy intensity (per 1 kg of product)	MJ	4.1	–

The products meet the requirements for materials intended for paved roads fabrication, where the load resistance is at least 2.5 MPa. Good mechanical properties of products correspond to the resistance to changing weather conditions. The results of measurements of frost resistance and water absorption showed lower values than the limit.

Other researchers who used granular sludge vitrification received replacement products, such as construction aggregates used in construction [5]. This aggregate meets all environmental requirements and has properties similar to LECA.

In measuring, the leaching of heavy metal ions in aqueous extracts has also been lower than limit values (Table 4). This means that the vitrified product is safe for the environment.

Table 4. Leaching heavy metal ions in aqueous extracts of vitrified products

Element	Measured values [mg·dm^{-3}]	Acceptable content [mg·dm^{-3}]
Cadmium	0.002	<0.02
Mercury	0.003	<0.05
Chromium	0.006	<0.5
Lead	0.022	<0.5
Copper	0.055	<0.5
Zinc	0.071	<2.0
Nickel	0.092	<0.5

It was confirmed that heavy metal compounds are built permanently into the structure of crystalline silicate and are not washed out. The results presented showed that the use of vitrification significantly reduces heavy metals leaching from waste containing fly ash from the incineration of sewage sludge.

Similar results were obtained in the study concerning vitrification of fly ash from the combustion of coal dust and coal, where resistance heating in a ceramic crucible was explored for the melting of unmodified fly ash [8]. The only drawback was the necessity of incurring significant energy expenditure per unit mass of product.

Performed measurements and calculations indicate the possibility of obtaining less energy consumption (0.4 MJ per 1 kg of weight) of the proposed waste disposal method, compared to the method described in the literature [8]. The composition of the mixture of modified ash processed to form a lump affects reducing energy consumption Adding the corresponding fluxes to the mix helped lower heating temperature by about 300°C compared to typical conditions.

CONCLUSIONS

On the basis of the results we formulated the following conclusions:

1. Sinters produced from the ashes from sewage sludge incineration by vitrification are environmentally safe products, and dangerous substances present in them are not degraded or washed away.
2. The products are suitable for widespread use as a replacement for aggregate based course construction of paved roads, embankments and banks.

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BADANIA PRZYDATNOŚCI WITRYFIKACJI POPIOŁÓW LOTNYCH ZE SPALANIA OSADÓW ŚCIEKOWYCH

W publikacji przedstawiono wyniki wstępnych badań właściwości wyrobów powstałych przez zeszkliwienie odpadów zawierających popioły lotne ze spalania osadów ściekowych. Wykonane testy wymywalności substancji niebezpiecznych z popiołów oraz wyniki innych badań laboratoryjnych potwierdziły skuteczność stosowania witryfikacji. Stwierdzono, że uzyskane produkty (spieki) mogą być przeznaczone do stosowania jako zamiennik kruszywa na podbudowy drogowe.