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Recycling of sand sludge as a resource for lightweight aggregates

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ABSTRACT

This paper reports the results of investigations on manufacturing lightweight aggregate from sand sludge. Sand sludge is a waste product from crushing and screening plants for sand and gravel production. Preliminary studies demonstrate the feasibility of recycling sand sludge into lightweight aggregates. The properties of lightweight aggregates from sand sludge depend on both, the preliminary firing temperature of the frit and the foaming temperature of the green granules. Increasing the firing temperature of the frit from 800 to 900 °C, the compressive strength, and the bulk and relative density of the granulated foam material decrease on the average by a factor of two, the water absorption decreases by 1%. The lightweight aggregates, derived from sand sludge at a temperature of 950 °C, have a bulk density of 330 kg/m^3, a compressive strength of 0.18 MPa and a water absorption of 0.1%.

1. Introduction

The production of lightweight and efficient building materials, in particular of lightweight granulated materials, is a constant and modern subject of scientific investigations. A promising solution is the development of porous materials under use of regionally available primary and recycled raw materials. Processing of industrial waste is an important topic not only from the point of view of reducing dangerous environmental pollution, but also in view of their potential beneficial use as an alternative source of raw materials. Therefore as initial raw materials for producing heat-insulating materials the preference is given to technogenic and substandard raw materials. The most frequently used lightweight aggregates are made from expanded clay, shale, perlite, vermiculite and different kinds of sintered waste. The publications of authors [1–2] suggest to use building wastes in the production of aggregates for concrete. The results of studies in which concrete aggregates were obtained from ash waste are presented in articles [3–9].

Well known are the investigations in which the use of different types of sludge wastes was proposed for the production of construction materials. For example, authors [10] write about the possibility of using sludge from the decorative quartz industry in hot bituminous mixes. Also, sludge, appearing as a by-product of chemical mechanical polishing in the integrated-circuit industry can be beneficially used in the production of construction materials [11]. Publications [12–19] cover an investigation of using sewage sludge in the production of lightweight aggregates.

A promising alternative raw material that in the past has attracted little interest is sand sludge. According to the Federal Institute for Geosciences and Natural Resources of Germany, approx. 50 million t. per year of sand sludge accrue in Central Europe, most of which remains unused. Estimations say that less than 0.7% (approx. 100,000 t per year) are presently fed back into industrial application, part of it is used in the brick industry [20]. Sand and gravel are won as a rule in opencast mining and are processed in processing plants. There the sand and gravel are washed, classified by particle size and the ultrafines are separated in suspension. This water solid mixture, the washing sand sludge, is disposed of mostly in nearby retention ponds [21].

The objective of the present research work was to develop lightweight aggregates using sand sludge as the main component in the raw mix and to characterize the properties of the materials produced. The research programme also included the production of granulated lightweight material, analogous to granulated foam glass, at temperatures below 950 °C. It is known that foam glass represents a high-performance material, with high durability, fire-resistance and ecological compatibility. The industrial technology of foam glass production is based on the use of glass waste or frit of compositions of sheet or container glasses.

When the temperatures necessary to reach the pyroplastical state of the melt and active formation of a gas phase coincide, the mix foams and stabilizes with the subsequent decrease of temperature. The high dispersity of sand sludge allows to expect the possibility of a low-temperature production of the frit. The results of preliminary studies are encouraging, since they confirm the possibility of using this type of raw material for the production

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of lightweight granulated material, that can be used as an aggregate for concrete and as a heat insulation filler.

2. Raw materials

The mineralogical composition of sand sludge represents a mixture of quartz, feldspar, different clay minerals, carbonates and oxides. Fig. 1a) shows its typical XRD pattern. The chemical composition of the sand sludge is shown in Table 1. The granulometric composition of sand sludge covers the particle size range 2–63 μm [20].

To lower the fusion temperature of the mixture, high purity soda ash (Na_2CO_3 > 99%) was added as a fusion agent.

As a foaming agent in the production of lightweight aggregate served carbon black type 220 (ASTM D1765). This carbon black represents technical highly active carbon with a high dispersity and high structural properties, obtained from thermal-oxidative decomposition of liquid hydrocarbon raw materials. The specific surface of carbon black is of the order of $1.14 \cdot 10^5$ m^2/kg.

3. Results and discussion

3.1. Influence of firing temperature of raw material mixture and properties of lightweight aggregate

Lightweight aggregates like granulated foam glass, represent a porous amorphous material, the synthesis of which is based on calculations of the glass technology. For the synthesis of glass with a defined composition it is necessary to strictly fulfill the following conditions.

The first condition, defining the component composition of the mix, is to ensure a sufficient supply of glass forming oxides (60–75 wt.%) and of fluxing oxides (13–22 wt.%). In addition it one must take into account that foaming of silicate glasses occurs at a viscosity of 10^5–10^7 Pa s. It is therefore necessary to apply glasses reaching such a viscosity at temperatures of 750–900 °C. Beforehand it is possible to estimate the viscous characteristics of glass by the viscosity module of its components: the value has to be within the limits 1.6–1.8 [22].

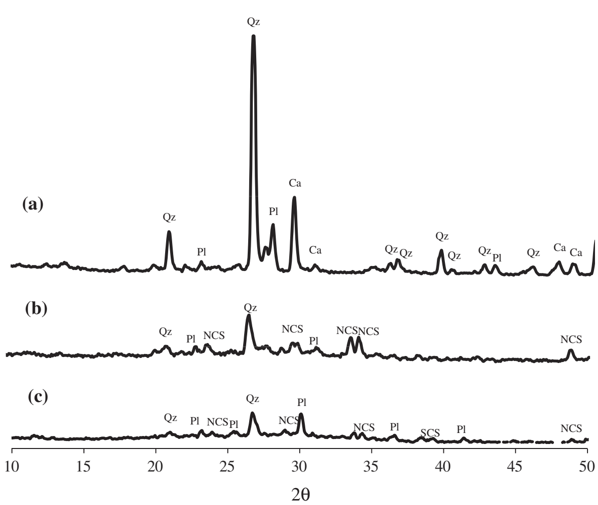

Fig. 1. X-ray diffraction pattern (Cu Ka) for: (a) sand sludge, (b) frit after 900 °C and (c) lightweight aggregate: Qz – Quartz; Pl – Plagioclase; Ca – Calcite; NCS – sodium calcium silicate $Na_2CaSi_3O_8$.

The second condition relating to the choice of the chemical composition of the frit is the amount of formed melt >70%, at a temperature less 900 °C, which was established on the basis of results of earlier experiments [23].

The third condition, which needs to be fulfilled with respect to the chemical composition of the frit, is the hydrolytic stability of the glass and presence of a sufficient amount of an active oxidizing component necessary to trigger foaming reactions. The composition of the raw materials (sand sludge) is characterized by a rather low amount of the main glass forming oxide (SiO_2) and a rather high amount of impurities in the form of alkaline earth metal oxides, aluminum and iron (Table 1) oxides. The composition of glass calculated for this mix, has the following content of oxides: SiO_2–66.3; Na_2O–13.4; CaO–6.5; Al_2O_3–6.8; Fe_2O_3–3.7; K_2O–1.8; MgO–0.8; MnO–0.1; TiO_2–0.5. The viscosity module predicted by standard calculations is 1.8, which falls into the recommended interval mentioned above.

$$M_v = (M_{SiO_2} + 2M_{Al_2O_3})/(2M_{Fe_2O_3} + M_{CaO} + M_{MgO} + 2M_{K_2O} + 2M_{Na_2O}) \tag{1}$$

where M_v is the viscosity module and M_{RmOn} is the amount of corresponding oxides, wt.%.

The first research task was to identify the optimal temperature regimes for the preliminary firing of the raw material mixture and later for the foaming of the green granules. To prepare the targeted lightweight aggregate, sand sludge was mixed with soda and then the mixture was fritted alternatively at 800, 825, 850 and 900 °C with isothermal holding times of 1 h.

The mix composition was identical for all rates of preliminary sintering: 80% of sand sludge and 20% of soda as a fluxing additive. After preliminary firing the received frit was milled, and mixed with a foaming additive (0.5%). For better understanding of the thermal processes proceeding during the foaming process of the formed granules Differential Thermal Analyses (DTA) was carried out, using a TA-Instruments TG *SDT Q600* thermo gravimetric analyzer. Fig. 2 shows the results of synchronous thermal analyses of the raw mix with the foaming agent after preliminary firing at 800, 825, 850 and 900 °C.

On all traces there are exothermic and endothermic effects, due to oxidations of the foaming agent and melting of a glass phase. It has been found experimentally that when rising the firing temperature of the frit, the temperature of the exothermic effect is displaced towards higher values. For example for a mix from low-temperature frit (800 °C) the exothermic effect is found for a temperature of 463.7 °C and for the frit obtained at 900 °C, the temperature is 498.6 °C. This effect is provoked by the different phase compositions of the frits. Shift of the oxidation temperature towards higher values is favorable for the foaming process since the probability of early burning out of the foaming additive decreases. The total weight loss of the frit sintered at low-temperature (800 °C) is 5 times higher than for the mix prepared from the frit at a temperature of 900 °C. In addition, DTA curves of mixes from low-temperature frits (800 and 825 °C) show several endothermic effects, while for frits with a temperature of 850 and 900 °C only one is observed, which points to their higher heterogeneity and presence of several phases, differing by their melting temperature.

Table 1
Chemical composition of the sand sludge.

Oxide content (wt.%)									
SiO_2	TiO_2	Al_2O_3	Fe_2O_3	CaO + MgO	MnO	R_2O	P_2O_5	SO_3	Loss on ignition
69.67	0.47	7.12	3.93	7.75	0.09	2.66	0.15	0.03	0.16