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ANALYSIS OF PHYSICAL AND MECHANICAL PROPERTIES OF LIGHTWEIGHT AGGREGATE MODIFIED WITH SEWAGE SLUDGE

ANALIZA FIZYCZNO-MECHANICZNYCH WŁAŚCIWOŚCI KERAMZYTU MODYFIKOWANEGO OSADAMI ŚCIEKOWYMI

Abstract: In recent years an increasing activity of sewage sludge management strategy is observed. This is due to EU legislation in the field of environmental protection, which constrains depositing this kind of waste. Sewage sludge is an organic-mineral material separated during the wastewater treatment. Because of physico-mechanical properties of the sewage sludge and the threat it can pose to human health and the environment, it has to be carefully processed before it is ultimately disposed of. In practice, there exist two directions of treatment of sewage sludge: natural management, which is covered by strict legislation, and combustion, which has certain advantages and disadvantages. Due to the above-mentioned legislation and EU standards in the field of environment protection, the sewage sludge management has become a major economical, ecological and technical problem. Thus, it is necessary to search for new methods of its utilization, independent of the present solutions. One of the method of utilization of the sewage sludge is production of the lightweight aggregate as a swelling agent, which creates the porous structure of the ceramic material during sintering. This paper presents the study of the basic physical and mechanical properties of lightweight aggregate derived from sewage sludge and clay. The aggregate was obtain in the forming method and sintering in 1150°C. Evaluation of physical properties was conducted on the basis of parameters such as specific density, bulk and volumetric density, porosity, water absorption. Mechanical properties of the aggregate was determined on the basis of resistance to crushing, abrasion in the Los Angeles drum, and frost resistance. Moreover, the removal of heavy metals from the extracts of aggregates was determined. The obtained results show that the lightweight aggregate with addition of sewage sludge meets the basic requirements for materials used in construction.

Keywords: sewage sludge, LECA, physical and mechanical properties of lightweight aggregate

Introduction

Sewage sludge is organic and mineral matter extracted from sewage in the course of its treatment. Due to its physical-chemical properties and a threat that it may pose to human health and the environment it must be subjected to appropriate processing by means of which it is finally disposed of. Pursuant to the Regulation of the Minister of Environment of 27 September 2001 on waste (Journal of Laws No. 112, 1206 of 8.10.2001), sewage sludge belongs to a group of 19 as waste from installations and equipment used for management of waste from sewage treatment plants, drinking water treatment and water for industrial purposes. EU legal regulations on environmental protection limit the possibility to store sewage. Ever-increasing quality requirements limit its use in agriculture. Admissible amounts of chemicals that sewage sludge may contain, are strictly defined by the standards such as *eg* Directive on Urban Waste Water Treatment 91/271/EEC [1] and its amendment - Directive 98/15/EC, "Sewage Sludge Directive" - 86/278/EEC [2], the directive which limits the use of sewage sludge in agriculture - 91/692/EEC, Directive on waste -

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2008/98/EC). The most significant consequence of another Directive on waste disposal - 99/31/EC [3] and the Minister of Economy and Labour is a ban on storage of sewage sludge the combustion heat of which exceeds 6 MJ/kg d.m. which has been introduced since 1st January 2013. This parameter effectively limits the storage of raw sludge on the site other than a hazardous waste landfill. In practice, there are two ways of the final disposal of sewage sludge: natural development, which is subject to more and more rigorous law regulations and thermal utilization. One of the advantages of this method is a significant reduction in the volume of deposits after burning, no time limits in utilization and energy recycling. These technologies, however, have some drawbacks. These processes are complex and costly, and in the case of co-incineration of sludge with fuel may produce some problems in meeting the standards for flue gas emissions and technical conditions required for conducting the process correctly. Due to the above-mentioned legislation and standardization requirements of the EU in the field of environmental protection, sewage sludge management has become a major economic, environmental and technical concern.

There has been an increased activity observed with regard to sewage sludge management strategy over the last few years. One of the methods of using sewage sludge may be applying it in manufacture of lightweight aggregate [4-11].

Lightweight aggregate used in production of lightweight concrete is generally porous material, the water absorption of which is usually higher than that of normal aggregate, which has an effect on the microstructure of hardened cement paste and the interfacial zone. The interfacial zone has been considered the weakest zone in composite concrete in terms of mechanical strength and permeability to fluids [12].

Materials and test methods

Testing material for production of lightweight aggregate was sewage sludge taken from the municipal sewage treatment plant "Hajdow" in Lublin and clay from "Budy Mszczonowskie" bed. Sewage sludge was subjected to tests in order to determine chemical parameters. Sewage sludge samples were taken from the temporary storage site, and then dried to a constant weight at 110°C. Dried sludge was ground and then added to clay (90% by weight) in the amount of 10% by weight. The process of making the substance homogeneous consisted in mixing components with the corresponding portion of water until a plastic consistency has been achieved. Then the formed balls of 16 mm coarse fraction were dried to a state of air-dry and kept in a laboratory oven at 110°C for 2 h. Dried samples were placed in a chamber furnace and fired at 1150°C for 30 minutes. Aggregate obtained as a result thereof was tested in order to determine physical and mechanical characteristics according to the standards [13-18].

One used the micro scanning electron microscope (SEM) - FEG Quanta 200 to determine the form and morphology of major minerals and chemical composition in microprobe. It also allows for performing the analysis of chemical composition based on energy dispersive of X-ray (EDS by EDAX company). Samples for SEM tests were glued onto the carbon holder by means of carbon glue. Preparations were then sprayed in the vacuum coater with a carbon layer the thickness of which was about 50 nm.

X-ray phase analysis was carried out using X-ray diffraction powder method using X-ray diffractometer Philips X'Pert APD (Fig. 1) with a goniometer PW 3020 and a Cu lamp and a graphite monochromator. The scope of the analysis included 5-65 2θ angles. Treatment of the results was performed in Philips X'Pert software and ClayLab program ver. 1.0. Mineral phase identification was based on PCPDFWIN database ver. 1.30 formalized by JCPDS - ICDD.

Leachability of hazardous substances such as cadmium, chromium, copper, nickel, lead and zinc was determined on the basis of the standard [13], and concentrations of heavy metals by means of AAS method using a spectrophotometer.

Test results

Results of sewage sludge tests

Test results of sewage sludge from the sewage treatment plant "Hajdow" in Lublin indicate that moisture content of sludge is 80.43%, alkalinity - 750 mg $CaCO_3/dm^3$, pH - 7.68, LKT - 92 mg/dm^3, ChZT - 136423 mg O_2/dm^3, dry mass - 19.57%, loss on ignition - 60.65%, the residue on ignition - 39.35%, density - 0.795 g/cm^3. Test results of the presence of heavy metals in sewage sludge show a significant presence of zinc ions (1175 mg/kg d.m.) and copper ions (442 mg/kg d.m.). Chromium ions are present in an amount of 74 mg/kg d.m., nickel - 42 mg/kg d.m., lead - 25 mg/kg d.m., cadmium - 8 mg/kg d.m.

X-ray phase analysis

X-ray diffraction photograph of sample phase composition (clay and lightweight aggregate from clay + sewage sludge) shows angular positions and intensity of diffraction reflections (Figs. 1 and 2). Main mineral components of clay from "Budy Mszczonowskie" bed are clay minerals represented by illite, kaolinite, beidelite, which are accompanied by quartz in minor amounts. Crystalline phases were identified based on basic interplanar quantities d, which amounted to particular minerals as follows: for beidelite - 4.49 Å, for illite - 10.01 Å; for koalinite - 7.14 Å and quartz - 3.44; 4.26 Å.

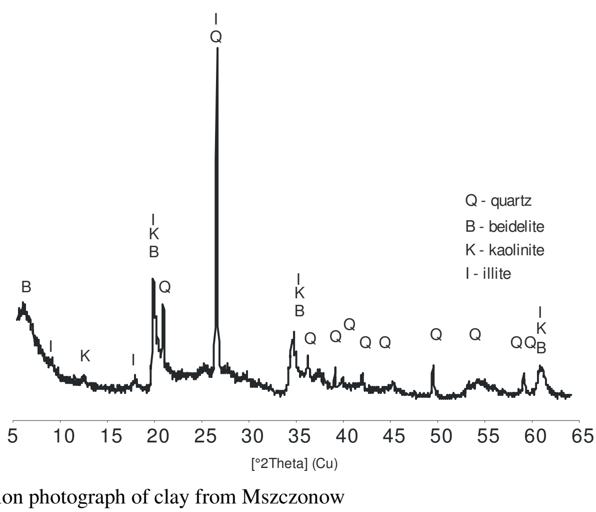

Fig. 1. X-ray diffraction photograph of clay from Mszczonow

It was found that in ceramic aggregate after firing at 1150°C there is mainly high temperature-type of quartz which is accompanied by mullite. As a result of heat treatment of sewage sludge there were also crystalline phases of hematite and graphite formed. Particular crystalline phases were identified through interplanar spacing: for quartz - 3.35 Å; 4.26 Å, for mullite - 5.40 Å, 3.40 Å, for hematite - 2.69 Å.

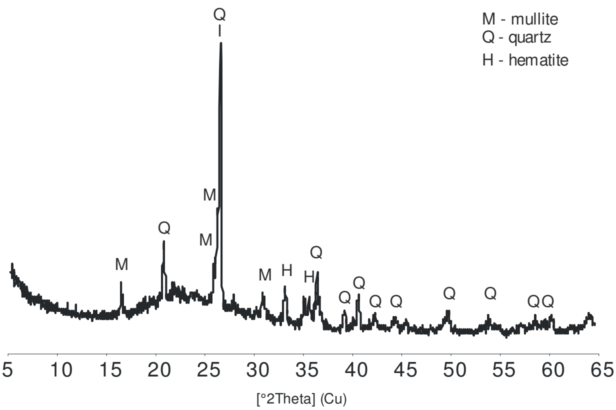

Fig. 2. X-ray diffraction photograph of mineral composition of lightweight aggregate fired at 1150°C

Scanning electron microscopy (*SEM*)

Lightweight aggregate is of porous structure and visible pores of spherical shape that are prevailing in the fired material are shown on Figures 3 and 4. The pore size varies and ranges from 2 µm to over 500 µm up to a few µm. Lightweight aggregate is characterized by compact and highly porous structure. Distribution of the pores is quite irregular.

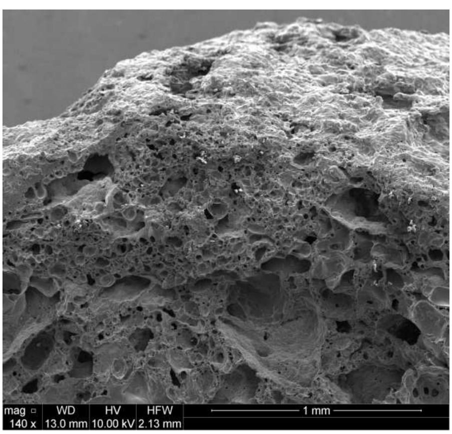

Fig. 3. Porous structure of lightweight aggregate fired at 1150°C, SEM above 140x

Fig. 4. Porous structure of lightweight aggregate fired at 1150°C, SEM above 8000x

Spectrum analysis of chemical composition of lightweight aggregate in a microprobe, fired at 1150°C (Figs. 5 and 6) indicates that predominant components are silicon, aluminum, iron. They are accompanied by potassium, calcium, magnesium. Chemical composition is as follows: SiO_2 - 53.6%; Fe_2O_3 - 9.33%; Al_2O_3 - 26.98%; K_2O - 5.58%; MgO - 2.15%; CaO - 2.36%.

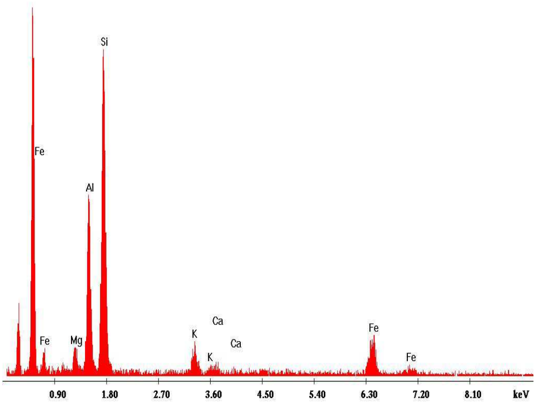

Fig. 5. Spectrum of chemical composition

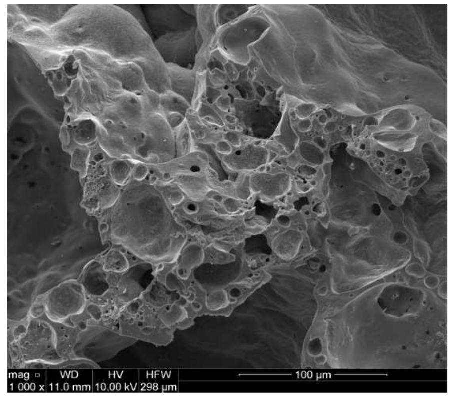

Fig. 6. Porous structure of lightweight aggregate fired at 1150°C, SEM above 8000x

Assessment of physical and mechanical properties of lightweight aggregate

Based on the results of the two samples taken and an arithmetic mean of their values, density was 2.59 g/cm^3. This is a typical value for this type of aggregate. Apparent density of lightweight aggregate subjected to tests was 0.812 g/cm^3, and bulk density was 0.414 g/cm^3. This value is close to the lower limit for bulk density of lightweight aggregate.

Absorptivity determined on the basis of the arithmetic average was 16.2%. Water wetted wall surfaces of lightweight aggregate which has been fired mainly on its surface, it did not go into the inside of the closed pores. After removing the material from water it regained its dry state fairly quickly. Compared to the acceptable limit for lightweight aggregate (< 37%) it is much lower. The porosity of aggregate subjected to test was 40%. The value of this parameter for the types of lightweight aggregate which are commonly manufactured at the market ranges from 20 to 50%. This value provides adequate absorptivity, high diffusivity of water vapour as well as thermal and acoustic insulation. The temperature of firing the aggregate plays an important role as far as the number of pores and their sizes are concerned. Void content or voids between grains is at the level of 52% due to the grain size of only (16 mm). The result obtained indicates that aggregate can be used in thermal insulation of roofs.

Frost-resistance of aggregate does not exceed 1%. The aggregate grain did not show any occurrence of cracks after the test. The aggregate is characterized by high porosity and large pore sizes. Water penetrating the grain probably has not filled in the whole surface of pores therefore it did not cause any damage to aggregate after freezing. Abrasion value obtained for the tested aggregate represents a high, unfavourable level. Such a large mass loss proves a very low resistance of aggregate to interaction of abrasive nature. Aggregate subjected to tests can be classified as LA80 as declared, therefore it cannot be used in road construction. Leachability measurements of chromium, cadmium, copper, nickel, lead and zinc in water extracts showed that the presence of metals is much smaller than it is tolerable (Table 1).

Table 1

Leaching of heavy metals from water extracts

Element	Concentration in extracts [mg/dm^3]	Values admissible for aggregate [mg/dm^3]
Cu(II)	0.015	< 0.5
Zn(II)	0.011	< 2.0
Cd(II)	0.001	< 0.02
Cr(II)	0.001	< 0.5
Ni(II)	0.036	< 0.5
Pb(II)	0.001	< 0.5

This means that you can use the tested aggregate as fully ecological building material of full value.

Conclusions

One obtained aggregate having good physical properties, of apparent density of 0.812 g/cm^3 and bulk density of 0.415 g/cm^3, absorptivity of 16.2%, porosity of 40%, void content of 52%, no coloring compounds. These results allow the use of lightweight aggregate modified with municipal sewage sludge for production of lightweight concrete. Appropriate porosity and void content also enable to use thereof to produce insulating concrete, and due to the lower water absorptivity and frost resistance compared to the standard lightweight aggregate, it should also be suitable as aggregate for concrete in moisture conditions. Considering many of the advantages, the lightweight aggregate obtained should be used in energy-saving building engineering, inter alia, in production of lightweight concrete, wall blocks, or as insulation for floors, ceilings.

The studies undertaken through developing the concept of lightweight energy-saving aggregate production from raw materials obtained from sewage sludge taken from sewage treatment plant aims at raising awareness of energy saving and environmental protection, as well as implementation of environment-friendly technologies in construction engineering.

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ANALIZA FIZYCZNO-MECHANICZNYCH WŁAŚCIWOŚCI KERAMZYTU MODYFIKOWANEGO OSADAMI ŚCIEKOWYMI

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Abstrakt: W ostatnich latach obserwuje się wzmożoną aktywność strategii zagospodarowania osadów ściekowych. Wynika to z przepisów prawnych UE w zakresie ochrony środowiska, które ograniczają możliwości ich składowania. Osady ściekowe są organiczno-mineralną materią wyodrębnioną ze ścieków w trakcie ich oczyszczania. Z uwagi na swoje właściwości fizykochemiczne oraz zagrożenie, jakie mogą stwarzać dla zdrowia ludzi i środowiska naturalnego, muszą być poddawane odpowiedniej przeróbce, za pomocą której są ostatecznie unieszkodliwiane. W praktyce istnieją dwa kierunki unieszkodliwiania osadów ściekowych: przyrodnicze zagospodarowanie, które objęte jest coraz większym rygorem przepisów prawnych, termiczna utylizacja, która ma zarówno zalety, jak i wady. Ze względu na wymienione powyżej prawodawstwo oraz standaryzację wymagań UE w dziedzinie ochrony środowiska zagospodarowanie osadów ściekowych stało się istotnym problemem ekonomicznym, ekologicznym oraz technicznym. Wzmaga to konieczność poszukiwania nowych, obok już istniejących rozwiązań, kierunków ich unieszkodliwiania. Jedną z metod wykorzystania osadów ściekowych może być zastosowanie ich do wytwarzania kruszywa lekkiego jako dodatku spęczniającego, który w warunkach wypalania prowadzi do utworzenia silnie porowatej tekstury spieku ceramicznego. Artykuł przedstawia badania podstawowych cech fizycznych oraz mechanicznych kruszywa lekkiego otrzymanego z osadów ściekowych i gliny. Kruszywo uzyskano metodą plastyczną przez wypalenie w temperaturze 1150°C. Oceny właściwości fizycznych dokonano na podstawie takich parametrów, jak gęstość właściwa, gęstość objętościowa i nasypowa, porowatość, nasiąkliwość. Cechy mechaniczne kruszywa określono na podstawie wytrzymałości na miażdżenie, ścieralności w bębnie Los Angeles, mrozoodporności. Dodatkowo określono wymywanie metali ciężkich w wyciągach z kruszyw. Badane właściwości wskazują, że otrzymane kruszywo keramzytowe z dodatkiem osadu ściekowego spełnia podstawowe wymagania stawiane materiałom stosowanym w budownictwie.

Słowa kluczowe: osady ściekowe, keramzyt, cechy fizyczne i mechaniczne kruszyw lekkich