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ANALYSIS OF HEAT-MOISTURE PROPERTIES OF HYDROPHOBISED GRAVELITE-CONCRETE WITH SEWAGE SLUDGE

ANALIZA CECH CIEPLNO-WILGOTNOŚCIOWYCH HYDROFOBIZOWANYCH KERAMZYTOBETONÓW Z OSADEM ŚCIEKOWYM

Abstract: The article presents the laboratory examinations of the basic physical parameters of gravelite-concrete modified by municipal sewage sludge and gravelite-concrete, obtained of light aggregates, commonly applied in Polish building market. To decrease water absorptivity of the concrete blocks, the admixture of water emulsion of reactive polisiloxanes was applied. For the presented blocks, capillary rise process was monitored together with moisture influence on heat conductivity coefficient λ determined using TDR probes and plate apparatus. Analysis of heat-moisture properties of concrete confirmed usefulness of gravelite with sewage sludge addition for further production.

Keywords: capillary rise, heat conductivity coefficient, gravelite-concrete, hydrophobisation

Introduction

Production of energy-saving and ecological building materials becomes a common technology to improve energetic effectiveness of the buildings according to European Union Directive 2006/32/WE3. One of the popular materials applied for the energy-saving civil engineering is gravelite-concrete, especially due to its thermal and moisture parameters.

Increased environmental and economic benefits can be achieved only if for gravelite-concrete production waste materials will be used [1-3]. To product gravelite-concrete, more often light aggregates, modified with municipal sewage sludge.

Sewage sludge may threat human health and thus should be suitably proceeded. Acts and regulations imposed by European Union limit sewage sludge deposition on landfills and its reuse in agriculture. One of the common utilization methods is application for production of ceramic materials [4, 5] and energy-saving gravelite-concrete blocks [6, 7]. Unfortunately sewage sludge is characterized by high moisture absorptivity, being the result of the structure of light aggregates. It is a serious problem in composition of the gravelite-concrete mixtures and ready-products because it intensifies transport of water due to capillary forces. It essentially influences heat flow process by the increase of the heat conductivity of the materials.

Differences between volumetric densities of the light aggregates and cement mortar cause the aggregates to flow out when cement mortar has no suitable viscosity. To minimize unfavorable phenomenon of water subtraction required for hydration process by the gravelite, several procedures should be conducted. One of them is initial wetting to

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protect the aggregates from autogenic contraction. Other solution is to cover the aggregates with cement grout, that provides lower water absorptivity of the aggregates, increases the density of particles and thus essentially influences concrete strength. A new technology is aggregates impregnation, that closes air gaps preventing them from water penetration with constant adherence of the particles to the cement matrix [8, 9].

The results of the present research can be possibly applied to establish guidelines for practical applications of lightweight concrete supplemented with sewage sludge foamed by hydrophobic agent, which has slightly different parameters compared to traditional lightweight concrete.

Materials and methods

Two types of gravelite-concrete samples were prepared, that differed in aggregates type. First type of aggregates were hand-made of clay from Light Aggregates Company “Keramzyt” in Mszczonow, Poland and from 10% additives of sewage sludge from municipal wastewater treatment plant “Hajdow” in Lublin, Poland. Sewage sludge from the Sewage Treatment Plant "Hajdow" in Lublin was described by following parameters: moisture content of sludge was 80.43%, alkalinity - 750 mg $CaCO_3/dm^3$, pH 7.68, VFAs - 92 mg/dm^3, COD - 136.423 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. 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 was based on mixing components with the corresponding portion of water until a plastic consistency was 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.

Second type of aggregates came from Ligth Aggregates Company “Keramzyt” in Mszczonow, Poland. Basic characteristics of the applied aggregates are presented in Table 1.

Table 1

Basic characteristics of gravelite applied for research

Type of aggregates	Density [g/cm^3]	Apparent density [g/cm^3]	Absorptivity [%]	Porosity [%]
Gravelite from Mszczonow	2.48	1.050	20	30.0
Gravelite with sewage sludge	2.59	0.812	16.2	40.0

Samples with the following dimensions: 150×150×150 mm were formed directly after concrete compounds had been mixed. They were condensed in two layers by vibrations until cement grout appeared at the surface of the mortar. The samples were disassembled after 24 hours of maturation and placed in water basin according to the PN-EN 206:2014-4 [10] standard until full average strength was reached (examined samples age - 28 days).

Within the experiment the following measurements were conducted:

- Real density was determined using PN-EN 1936:2010 [11] standard A - method with pycnometer, in laboratory conditions, at the temperature of 20°C.

- Apparent density determination were conducted after 28 days of concrete maturation. Apparent volume was determined using the following standards: PN-EN 1389:2005 [12], PN-EN 12390-7:2011P [13].
- Absorptivity.
- Porosity.
- Capillary rise, determined using the TDR (Time Domain Reflectometry) technique, previously described in the following papers [14, 15].
- Microstructure of gravelite-concrete using SEM (Scanning Electron Microscope).
- Heat Conductivity Coefficient using FOX 314 by Laser Comp, plate apparatus.

It is worth mentioning in here, that the applied TDR (Fig. 1) technology required modification of the traditional reflectometric sensors which in standard version are small and not stiff enough to be inserted into the hard structure of gravelite-concrete. For that aim there were intentionally developed TDR sensors that could be used in this particular experiment. Heads of the manufactured sensors were made of polyamide cylinders with the diameter of 46 mm and the measuring elements were made of steel rods 50 mm long and 5 mm wide in diameter. Spacing between the rods was equal 24 mm. Probes were inserted into the examined sample in the following levels: 5 cm above water table and 10 cm above water table. Duration of the whole experiment was set to 350 hours until no significant water increase was observed. Capillary suction experiment was conducted on both samples (i) gravelite-concrete with aggregates from Mszczonow and (ii) gravelite concrete with aggregates from sewage sludge.

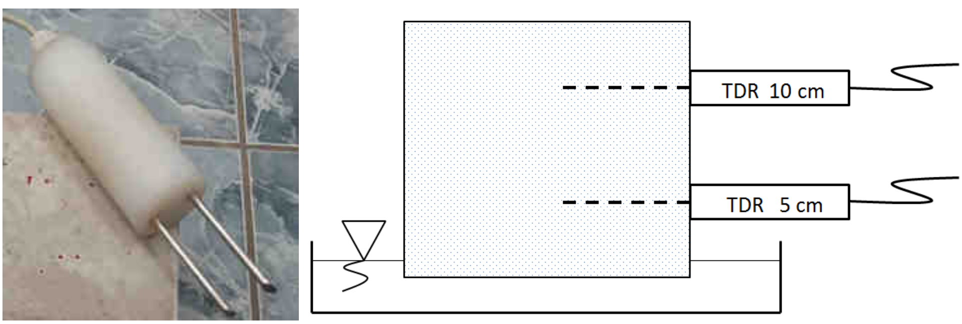

Fig. 1. Capillary uptake process determination - probe used for experiment and schematic view of measuring setup

To measure heat conductivity coefficient using FOX apparatus, 3 plates of each gravelite-concrete type were prepared. The dimension of each plate was 300 × 300 × 50 mm. Examinations were conducted for both dry samples and 3% moist (achieved by concrete saturation in a space with relative humidity about 70%). Period assumed for concretes saturation was established as 4 weeks. To determine heat conductivity coefficient of the material it was set the temperature gradient of 20°C between heating and cooling plate. For that aim the following temperatures were applied: 20°C for heating plate and 0°C for the cooling plate. Average temperature was equal 10°C.

Results and discussion

Obtained results are presented in Table 2.

Table 2

Physical properties of the examined gravelite-concretes

Type of concrete	Density [g/cm^3]	Apparent density [g/cm^3]	Absorptivity [%]	Porosity [%]	Heat conductivity λ [W/mK]	
					Dry	3% moist
With aggregates from Mszczonow	2376	1442	7	39.3	0.67	0.72
With aggregates from sewage sludge	2450	1344	4	45.1	0.52	0.58

According to the above described measurements and calculations, the real mass of the concrete unit (volumetric density) equals ρ_p = 1344-1442 kg/m^3. Determined with pycnometer real density equals ρ = 2376 and 2450 kg/m^3. Percentage volume of pores in concrete with sewage sludge reaches 45.1 and is 12.86% greater from light concrete with aggregates from Mszczonow.

Heat conductivity coefficient λ of gravelite-concrete with aggregates from Mszczonow in dry state is about 7% smaller comparing to moist material (3% of moisture) and 10% smaller comparing to concrete with sewage sludge. Difference between examined light concretes with moisture equal 3% is about 19.44% and indicates better thermal parameters of gravelite-concrete with sewage sludge.

Results of capillary rise phenomenon determined using TDR method are presented on Figure 2. Conducted research confirmed the decreased capillary parameters of the examined concretes.

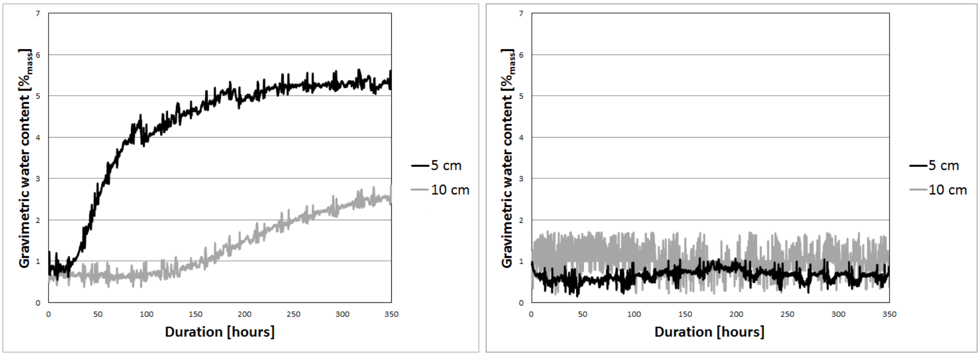

Fig. 2. Capillary rise phenomenon determined within the described research. Left - gravelite-concrete with aggregates from Mszczonow, right - gravelite concrete with aggregates from sewage sludge

In case of the sample with aggregates from Mszczonow the progress of the process was slow. The first moisture increase readouts were observed by the probe placed at level of 5 cm above water table. It was noticed after about 24 hours since the beginning of the experiment. Within next 150 hours the progress of the phenomenon was significant to reach the level of 5%. Maximum water content read by the bottom probe was reached after the period of about 250 hours and it was still below 6%. It should be mentioned that this value was close to maximum material absorptivity (7%). In case of the second probe, mounted at the level of 10 cm above water table, moisture increase was significantly slower. The first water appearance was read after about 150 hours since the experiment was started. Maximum moisture read by the reflectometer was about 2.5%.

In case of the second sample - with aggregates from sewage sludge almost no significant water increase was observed. Readouts of two probes were unstable and varying between 0 and 2%. This ought to be considered as standard uncertainty of the TDR method, which according to many literature sources is about 2% [16, 17].

Scanning Electron Microscope (SEM) research was conducted on samples of gravelite-concrete obtained from aggregates modified with municipal sewage sludge and aggregates from Mszczonow. SEM photographs of microstructure of cement mortars are supplemented with EDS diagrams. Hardened cement mortar from Portland cement consists of 70% of hydrated calcium silicates, so called C-S-H phases. About 30% are calcium hydroxide and products of aluminate hydration and calcium aluminate-ferrate. Microscopic research confirmed good adhesion in contact points between gravelite aggregates and cement mortar. No empty gaps, cracks or scratches were noticed in the above mentioned contact points (Fig. 3).

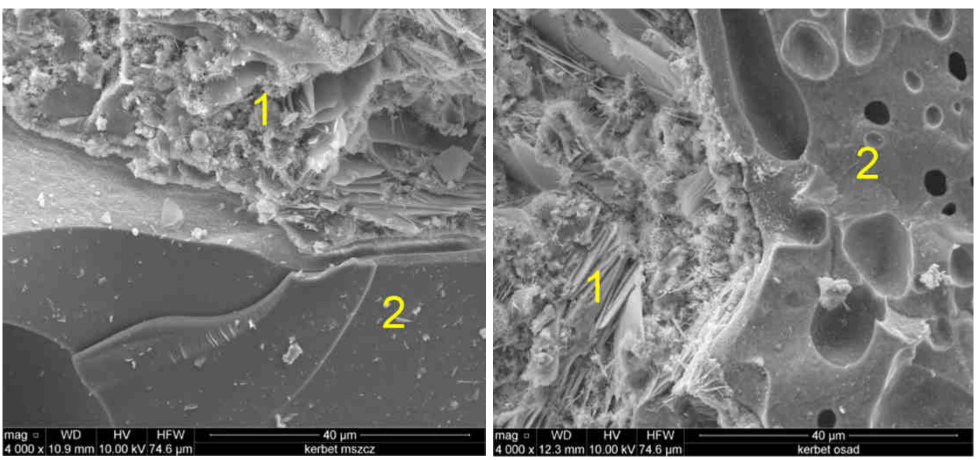

Fig. 3. SEM investigation in contact point: left - between gravelite aggregates from Mszczonow and cement mortar supplemented with spectrum of chemical composition; right - between gravelite with sewage sludge and cement mortar supplemented with spectrum of chemical composition (1 - mortar, 2 - gravelite)

Conclusions

By the use of gravelite-concrete modified with sewage sludge it is possible to produce lightweight concrete with the apparent densities of 1400-1960 kg/m^3.

Supplementation with sewage sludge caused the decrease of material apparent density for about 7% and the increase of total porosity for 12.86% comparing to the concrete from gravelite available on building market. This was also confirmed by verifications using SEM technique. Microscopic observations of contact points between gravelite aggregates and cement mortar confirmed good adhesion. No empty gaps, cracks or scratches were noticed in above mentioned contact points.

Absorptivity of both gravelite-concretes is between 3 and 7%, especially because of the application of hydrophobic preparation as concrete additive. It should be emphasized that gravelite with sewage sludge, due to greater absorptivity and porosity absorbed more impregnate which decreased the total absorptivity of light concrete for about 57%. Time Domain Reflectometry measurement of capillary rise phenomenon proved total inhibition of capillary rise process.

Sewage sludge additives in gravelite-concretes enable to decrease heat conductivity coefficient for about 7-10%.

Presented examinations proved that sewage sludge can be applied as an additive for light concretes production. Anyhow, to completely verify this conclusion it should be supplemented with strength examinations of concretes with sewage sludge additives.

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Abstrakt: Produkcja ekologicznych i energooszczędnych materiałów budowlanych staje się powszechną technologią poprawy efektywności energetycznej budynków zgodnie z przepisami dyrektywy UE 2006/32/WE3. Jednym z materiałów stosowanym w budownictwie energooszczędnym ze względu na swoje właściwości cieplno-wilgotnościowe jest keramzytobeton. Do otrzymywania keramzytobetonu coraz częściej stosuje się kruszywa lekkie modyfikowane komunalnym osadem ściekowym. Osady ściekowe stwarzają zagrożenie dla zdrowia ludzi i środowiska naturalnego, dlatego też muszą być poddawane odpowiedniej przeróbce. Jedną z metod ich utylizacji jest zagospodarowanie do produkcji energooszczędnych bloczków keramzytobetonowych. Często jednak charakteryzują się one wysoką nasiąkliwością, co powoduje transport wody podciąganej kapilarnie. Wpływa to w istotny sposób na proces przepływu ciepła, tym samym zwiększając kilkukrotnie przewodnictwo cieplne materiałów. Artykuł przedstawia badania podstawowych cech fizycznych keramzytobetonu modyfikowanego komunalnym osadem ściekowym oraz keramzytobetonu uzyskanego z kruszywa lekkiego powszechnie stosowanego na rynku. W celu obniżenia nasiąkliwości betonów jako domieszkę zastosowano wodną emulsję reaktywnych polisiloksanów. Dodatkowo wykonano pomiary podciągania kapilarnego oraz jego wpływu na współczynnik przewodzenia ciepła λ w próbkach modelowych przy wykorzystaniu sond TDR i aparatu płytowego. Analiza cech cieplno-wilgotnościowych betonów potwierdziła przydatność keramzytu z dodatkiem osadu ściekowego do ich produkcji.

Słowa kluczowe: podciąganie kapilarne, współczynnik przewodzenia ciepła, keramzytobeton, hydrofobizacja